SOME FACTORS AFFECTING GROWTH OF CITRUS ROOTSTOCK SEEDLINGS IN HAWAII

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Citrus production in Hawaii is limited to about 110 acres which are mostly on the island of Hawaii. In general orange quality falls short of mainland grown fruit. Citrus quality is affected by environmental factors such as temperature, moisture, nutritional status during development and the type of rootstock upon which it is grafted.

Troyer citrange (Poncirus Trifoliata Raf. X Citrus sinensis (Linn) Osbeck), Trifoliate orange (P. Trifoliata Raf.), and Cleopatra mandarin (C. reticulata Blanco) are desirable rootstocks because they are resistant to the tristeza virus and the gummosis fungus diseases (Phytophthora sp.) prevalent in Hawaii and because they favorably influence the quality characteristics of oranges and tangerines. They are not widely used, however, and the Trifoliate orange, which has the greatest beneficial influence upon fruit quality, is almost unknown. Because of the poor growth of Trifoliate before grafting, nurserymen do not use it as a rootstock in Hawaii.

Daylength in Hawaii varies only 2 hours between winter and summer, much less than in Southern California or Florida. Many soils are highly weathered and leached in Hawaii so that aluminum and manganese frequently reach toxic levels. The influence of high soil aluminum and manganese has not been studied as factors limiting growth and quality of citrus in

Hawaii.

These experiments were designed to study some of the possible causes of the poor growth of the Trifoliate orange in Hawaii. The effects of naturally occuring high levels of aluminum and manganese on nutrient availability and the influence of photoperiod on citrus seedling growth were investigated.

REVIEW OF LITERATURE

Influence of Rootstock on Scion in Citrus

Rapid development of the citrus industry during the last 20 years led to a search for better rootstocks. Extensive research has been conducted in improving the production and quality of citrus the world over. Although much progress has been made there is still room for improvement.

Although numerous earlier workers had shown the importance of seedling rootstocks, Hass (1945) reported that rootstock species influence the growth and inorganic composition of the scion. In 1947 he reported on a comparison of Trifoliate orange, Cleopatra mandarin, Troyer citrange and rough lemon as rootstocks for California conditions. Trifoliate orange and Troyer citrange were definitely superior to rough lemon for improving the quality of oranges and tangerines. The work of Hass was substantiated by Smith et al. (1948), Bitters and Batchelor (1950), Ford (1953) and Shannon and Zanpherir (1957). Wallace et al. (1953) added to this list the yield and quality of fruit and the susceptibility to various diseases. Chandler (1958) reported that Trifoliate, Troyer and Cleopatra rootstocks were resistant to tristeza virus and gummosis fungus diseases.

Bitters reported and Sinclair (1961) confirmed that Trifoliate orange and its hybrids are more susceptible than

are other rootstocks to boron deficiency and are highly susceptible to iron and zinc deficiencies. Severe copper deficiency has also been associated with Troyer rootstock. These differences were attributed to differential absorptive capacities among rootstocks for certain mineral elements which were manifested upon the scion variety. These differences may have been related to the interaction between root and soil cations (Jenny and Overstreet 1938). Wallace et al. (1953) suggested that rootstocks should be evaluated according to the properties of the soil.

Properties of Plant Roots

Knowledge of the exact mechanism whereby ions enter plant roots is still lacking. A contact phenomenon between plant roots and clay particles has been proposed by Jenny and Overstreet (1938). Williams and Coleman (1950) reported that plant root surfaces possess cation-exchange capacities (CEC) which may be measured by the absorption and release of various cations. The wide variations in nutrient uptake by plants appear to be related to great difference in CEC of plant roots. Cation-exchange capacities of the roots of dicotyledonous plants are generally higher than for monocots. This has led to the hypothesis that cation uptake is related to root CEC (Drake et al. 1951). Smith and Wallace (1954) reported that accumulation of cations is related to CEC of roots. Their findings showed that wheat exhibited a CEC of 9.0 and Larkspur 94.4 me/100g of oven-dry tissue. The

cation-exchange capacity of citrus was found to vary from 21.0 me for grapefruit to 32.0 me/100g for Trifoliate orange. High CEC values of roots have been related to the total nitrogen in the plants (McLean et al. 1956), the amount of organic acid excreted by species (Heintz 1961) and to the pectin content (Crooke et al. 1961).

Crooke and Knight (1962) reported that CEC of the roots is positively correlated with the total cation content, excess base, total trace elements, protein and ash. Epstein (1956), Laties (1959) and Black (1963) concluded that there appears to be no agreement concerning the significance of CEC of the roots to the nutrient uptake by plants. The exchange positions of ions on the roots are distinct and the ions from the soil can reach the sites of active transport by free diffusion through solution without necessarily becoming attached in exchangeable form. Hence, the cation-exchange capacities of roots appear to play no essential role in the transportation of ions from the soil solid phase into the interior of plant roots (Black 1963). Fox and Kacar (1964) stated that the root-surface relationships to nutrient uptake is not fully understood. However, factors which influence the kinds and amounts of ions at or near the root-surface must also influence ion absorption.

Crooke (1958) reported the effect of heavy metal on cation-exchange capacity of roots with emphasis on manganese, cobalt, copper, zinc, nickel. For the crops studied, excess

cobalt, zinc and nickel produced an increase and manganese a reduction in cation-exchange capacity of the roots. Excess copper produced an increase in root exchange in the case of oats and sunflower, and a reduction in the case of tomato, pea and bean. Mechlich and Reed (1948) concluded from their experiment that cation accumulation of plant species is related to the ability of roots to mobilize H-ions. They also reported that CEC of the soil surface influences the amount of cations taken up by plants.

Effect of soil pH on Growth and Development of Plants

Soil pH and fixation of nutrients have been shown to be important factors controlling availability and absorption of mineral elements by roots. An acid condition is unfavorable to the best development of physical and biological soil conditions and this influences the growth of plants (Truog 1918). Furthermore, it has been shown that acid soil is harmful for certain plants because plants do not get certain nutrients which are vital for their growth. He concluded that pH 6.5 is a favorable reaction for nutrient availability.

Rains et al. (1964) reported that H-ions may cause a general derangement of, or damage to, the ion absorption mechanisms. The nature of this injury is not known. However, features of the problem are: steadily declining absorption rates, leakiness, indiscriminate competition among ions and eventual death of the tissue. Some possible mechanisms of injury induced by H-ions are: denaturization

of proteins, nucleic acids, phospholipids, and other polymers involved in membrane structure and function, displacement by H-ions of essential co-factors from functional groups, suppression of ionization of weak acids and an increase in concentration of heavy metal ions in solution within the tissue.

Certain nutrients are readily leached from acid latosols. Still others become highly insoluble. Most elements are probably affected as to solubility by the reaction of the soil. Early studies of acid soil showed that some elements mainly calcium, phosphorus, magnesium, nitrogen and potassium would become less available when the soil becomes acid, while iron, aluminum, manganese, copper, zinc, and other heavy metals would become more available. The presence in the soil of soluble aluminum compounds has generally been associated with an acid condition in the soil.

The favorable pH range for citrus growth has been found to vary from soil to soil. Leibig *et al.* (1942), Parker (1948) and Martin (1960) reported that citrus orchards are grown throughout the world in soils with a pH range of 4.0 to 8.5. Martin and Page (1962) found maximum growth of orange seedlings at pH 5.7 to 6.5 and good growth from pH 4.8 to 7.4 in some soils. Thus pH *per se* could hardly be considered a major factor influencing citrus growth. Paul and Chapman (1944) concluded that pH values ranging from slightly below 4.0 to somewhat above pH 9.0 exerted no

appreciable direct ill effects on the growth of sweet-orange plants.

On the other hand, high soil acidity usually favors the accumulation and solubility of toxic organic and inorganic substances. Among these toxic substances soluble aluminum and manganese have been noted by Schmehl et al. (1950). They reported that toxicity was observed when the ratio of Ca/Mn was less than 75. The works of Wallace et al. (1945) and Hale and Heintze (1946) indicated that in acid soils manganese and aluminum toxicity is an important factor in causing injury to plant growth. Russell (1961) reported that the direct injury of acid soil to plant growth was by hydrogen ions, lack of available phosphorus, excess of soluble aluminum and biotic factors.

The presence of manganese and aluminum in Hawaiian soils has been demonstrated. Holmes et al. (1960) reported that Al_2O_3 content of the top soil of Kapaa was about 30%. Fox et al. (1962) showed a high phosphorus fixation in Kapaa soil. Suehisa et al. (1963) indicated high manganese dioxide as being a dominant characteristic for Wahiawa soil.

Effect of Aluminum and Iron on Phosphorus Availability

Studies of fixation and availability of plant nutrients in aluminous soils are numerous. For example, DeDatta et al. (1963)report that fixation of applied phosphorus in Kapaa soil was very high even when exchangeable aluminum was eliminated by liming.

Phosphorus in an aluminous soil precipitates as aluminum phosphate. Larsen et al. (1959) indicated that iron and aluminum ions which can hold phosphate can be present in different forms. In acid soil aluminum may be present in a film of hydrated oxides or as exchangeable cations. If an acid soil is limed, aluminum may be present as aluminum hydroxide. Fox et al. (1962) have shown how liming modifies the status of active aluminum in soil and its effect on solubility of phosphorus and its uptake by plants.

Influence of Soil Aluminum in Plant Growth

Although reports of numerous investigators showed aluminum toxicity to plants, the possible mechanisms of its toxicity to plants are opened to question. Magistad (1925) proposed that restricted lateral root development in rye grass was due to soluble aluminum rather than to an excess of hydrogen ion concentration. Field experiments and tissue analyses by Plucknett et al. (1963) indicated that restricted root development in Hawaii aluminum soils is due to phosphorus fixation rather than aluminum toxicity. Root injury due to aluminum toxicity has been reported by Lignon and Pierre (1932). Gilbert and Pember (1931) have observed symptoms of discolorations of roots from aluminum toxicity. Plucknett et al. (1963) proposed that staining of roots cannot be attributed to aluminum alone. Iron and other metals may also have the same effect. However, in a

rich aluminum soil much of the staining can be attributed to aluminum.

Hass (1936) has found a stimulating effect of aluminum on citrus root growth. Later, Liebig et al. (1942) proposed that the stimulating effect of aluminum on citrus growth is due to the antagonistic effect of aluminum on copper. In the absence of aluminum, 0.1ppm copper was toxic to valencia orange and lemon cuttings.

Role of Manganese in Plant Nutrition

Manganese, although considered a micro-nutrient element plays a very important role in plant nutrition. The essentiality of manganese for healthy citrus growth was apparently first shown by Hass (1932). Only a small quantity (20-90ppm) is adequate for satisfactory citrus growth as reported by Reuther et al. (1958).

Symptoms of manganese deficiency on citrus have been ascertained in most citrus growing areas of the world. In California, manganese deficiency may be masked by deficiencies of zinc and iron (Labanuskas 1962). In acid Florida soils, the inclusion of manganese sulfate in fertilizer has largely controlled the deficiency of this element. No report was found of manganese toxicity on citrus. This opens a field of interest to investigators and the result will be valuable to areas with similar conditions.

The complete role of manganese in plant nutrition has not yet been established, but certain functions have been

determined. It seems to be abundant in native plants and is vital to the functioning of enzyme systems. Manganese promotes IAA oxidation in the enzyme system of higher plants and appears essential for its action (Ray 1958).

Status of Manganese in acid soil and its effect on nutrient availability

An acid soil undoubtedly contributes to the solubility of manganese. Manganese tends to be oxidized at a higher soil pH and reduced at a lower pH (Christensen et al. 1950). They also reported a reduction of exchangeable manganese with an increase of soil moisture. Fujimoto and Sherman (1948) indicated that organic matter (sugarcane and pineapple leaves) in the soil increased exchangeable manganese. Manganese behaves the same as aluminum with respect to soil pH and solubility (Black 1963). The excess soluble manganese in an acid soil has been found to have an antogonistic effect on iron availability. In determining the state of oxidation of iron within plants, Somers and Shive (1942) found that the symptoms of iron chlorosis increased with increasing manganese content. The solubility of these two metals is influenced in the same general way by pH. However, in a high manganese soil, the iron is precipitated in an unavailable form (Johanson 1924). The manganese oxidized form of iron (ferric) is less available to plants than reduced form (ferrous). The excess manganese hinders the assimilation of iron by converting the available iron into the physiologically

inactive ferric condition. Hopkins (1930) showed that manganese may be physiologically effective on other ions.

Influence of soil manganese on plant growth

The status and behavior of manganese on growth of pineapple in Hawaiian soils is well known (Fujimoto and Sherman 1947, 1948). This work indicated that manganese toxicity was apparent in pineapple but not in sugarcane. Kelly (1909) and Johanson (1924) have made a thorough investigation of manganese influence on growth of pineapple. Many of these workers indicated that high soil manganese precipitates iron and distrubs the balance of iron to manganese.

Kelly (1920) surmised that some citrus species grown on manganese soils exhibited stunted growth and dieback. In certain instances the protoplasm had undergone changes. Occasionally, it drew away from the cells walls, the nuclei became brown and plasmolysis took place. Russell (1961) stated that excess manganese accumulates in all tissues and interferes with proper metabolism.

Leaf Sampling

Citrus leaf analyses have been widely used as a diagnostic tool for evaluating the nutritional status of citrus. Kelly and Cummins (1920) reported that the age of citrus leaves influences their composition. Haas and Halma (1931) reported that changes in the organic constituents of

citrus leaves were not seasonal but were related to the age of the leaves. On the basis of leaf analyses made by many workers, the leaf position and age are very important factors for obtaining valid data from tissue analyses. Cameron et al. (1952) found variations in the level of mineral contents within flushes, between flushes and between years. Robert and Sites (1956) observed wide variation in phosphorous, potassium and calcium content and to a lesser degree in nitrogen and magnesium contents between leaves from the tip and from the base of the same twigs.

The age of leaf was the most important factor influencing its mineral composition as noted by these workers. They have shown that the decrease in percentage of nitrogen, phosphorus, potassium, calcium and magnesium which accumulated when leaf size increased resulted from a rapid accumulation of carbohydrates. Reuther et al. (1958) have pointed out that unless the age and season of growth of citrus leaves are taken into account, uncertainty regarding the validity of conclusions based on leaf analysis will exist. They recommended that in order to secure representative samples from non-fruiting branches, 3 to 6 month old leaves are the most desirable. A plateau level exists for most of the measured elements during this period. Embleton et al. (1962) showed significant differences in nutrient concentrations of the orange leaves due to method of sampling.

Effect of photoperiod on plants

The term photoperiodism is generally applied to that phenomenon in which the relative length of day and night influence the development of plants and animals (Nitsch, 1957 and Salisbury, 1960).

In woody and herbaceous plants, the length of days and nights affects root initiation, shoot elongation, node formation, dormancy, winter hardiness and flowering.

Cuttings exposed to 10 or more hours of light daily developed roots more rapidly than cuttings under 8 hours (Snyder, 1955). The effect of photoperiod on rooting is seasonal and varies with the species (Lanphear and Meahl, 1961). Photoperiod of 18 and 24 hours during the fall generally did not affect the number of cuttings which rooted but did affect it significantly during late winter.

The vegetative growth of woody plants is influenced by daylength. Stem elongation and leaf number seemed to be directly proportional to the length of the day (Downs and Borthwick, 1956, and Nitsch 1957). Species vary in response to photoperiodism (Nitsch 1957, Piringer and Downs, 1959). Work with citrus, including Trifoliate, showed that the longer the photoperiod the more the total growth (Piringer, et al. 1961).

According to Kramer (1936), dormancy is not caused by any inherent rhythm in plants, but is produced by a complex of internal physico-chemical phenomena controlling growth. Wareing (1948) stated that long days break summer dormancy

more effectively than winter dormancy. In citrus short days did not cause dormancy but reduced the rate of growth.

Pinus resinosa seedlings exposed to freezing during winter made little or no growth during summer unless exposed to approximately 16 hour days (Gustafson, 1938). Lamerts (1941), Lesley (1944) and Weinberger (1950) working with apricots and peaches reported that plants with a long chilling requirement moved to a region where mild winters approach tropical conditions will not grow at the maximum rate. Regarding hardiness in citrus, grapefruit trees grafted on sour orange rootstocks exposed to 16 hour photoperiod were less cold hardy than those under short days (Young 1961).

Citrus flowering was reported by Furr et al. (1947) to be indeterminate with respect to photoperiod. However, salvia, verbina and petunia showed that when under long photoperiod it flowered sooner than under short photoperiod. Cathey and Piringer (1961) have shown that 8-hour day light with 8 hours of supplemental light induced flowering sooner than 8-hour photoperiods alone. They further indicated that incandescent lamps were much more effective than fluorescent ones in promoting growth. Maginnes and Langhans (1961) found similar results with snapdragons.

MATERIALS AND METHODS

Experiment 1. Effect of soil type and pH on the growth of Cleopatra mandarin, Troyer citrange and Trifoliate orange seedlings

Experimental Design

The scope of this investigation was to study the effect of two soil types on the growth of citrus seedlings. This study involved the use of Cleopatra, Troyer and Trifoliate orange seedlings and two soils at three pH levels. In order to determine factors affecting growth, a factorial arrangement of treatments (2x3x3) was used in a randomized complete block design. The experiment consisted of 18 treatments with 8 replications, a total of 144 seedlings.

Experimental Materials

Description of plants

The seedlings of Rubidoux Trifoliate orange (*Poncirus trifoliata*) and Troyer citrange (*Poncirus trifoliata* x *Citrus sinensis*) which were used for the investigation were imported from Thermal, California. Cleopatra mandarin (*Citrus reticulata*) were local seedlings.

1) *Cleopatra mandarin*. This rootstock is tolerant to diseases such as tristeza and resistant to scab and xyloporosis. It is hardy and drought-resistant and adapted to light sandy soils as reported by Chandler (1958).

Cleopatra is average in its contribution to quality and size of fruits as compared to other rootstocks (Cooper *et al.* 1952, Bitters and Batchelor 1951).

2) Trifoliate orange. This rootstock is adapted to fairly rich soils of low moisture content and is generally regarded as unadapted for use on dry, light sandy or calcareous soils. It is the most cold-resistant of citrus rootstocks and is deciduous. Batchelor and Webber (1948) quotes Hume (1926) as saying that Trifoliate has not responded satisfactorily to tropical growing conditions. It is resistant to gummosis fungus diseases and tristeza virus. However, it is highly susceptible to citrus canker and exocortis. It tends to have a dwarfing effect on tree size. Bitters and Batchelor (1951) and Cooper *et al.* (1952) showed that Trifoliate produces fruits with higher soluble solids, acid and the number of fruits per unit size of tree as compared to most other rootstocks.

3) Troyer citrange. Troyer is a hybrid of Trifoliate orange and Sweet orange (Washington navel). It has good vigor and grows well in the nursery. Although it has not been tested in as many parts of the world as other rootstocks, it is resistant to tristeza and gummosis but susceptible to exocortis. It is more cold resistant than the Sweet or Sour orange, Mandarins or Rough lemon and less resistant than the Trifoliate. Hamilton and Fukanaga (1962) reported that Troyer is better adapted to tropical growing conditions than Trifoliate orange as a rootstock. Fruits

produced from Troyer as a rootstock exhibited better quality than Sweet orange.

Description of Soils

Two diverse soil types were used in the experiments. One type, Kapaa, was obtained from the Kauai Branch Experiment Station and the other, Wahiawa silty clay, was obtained from the Poamaho Experimental Farm.

1) Kapaa silty clay. This soil is a well-drained Aluminous Humic Ferruginous Latosol developed in saprolitic ferruginous bauxite on gently sloping uplands on the island of Kauai. The soil was taken from the Kapaa Experiment Station which has an elevation of 500 feet and a mean annual rainfall of 100 inches. Holems et al. (1960) showed that the soil has a high concentration of gibbsite. DeDatta et al. (1963) reported that the Al_2O_3 content of the top soil was about 30% on an oven-dry basis. The water holding capacity was fairly low. The soils of this series are used mainly for pasture, non-irrigated sugarcane and pineapple.

2) Wahiawa silty clay. This soil is a red Low Humic Latosol and occurs in the vicinity of Wahiawa, on Oahu. The soil was taken from the Poamoho Experimental Farm which has a rainfall of 40 inches a year and an elevation of 860 feet above sea level. The mineralogical composition of the Low Humic Latosol group is: kaolinite (45-55 par cent including halloysite), hematite (15-25 per cent), allephane (5-10 per cent) and montmorillonite (Tamura et al. 1953). The Wahiawa soil also contains some illite. Kanehiro and

Sherman (1956) made a similar study and reported that the clay content may be as high as 80%. Kanehiro and Chang (1956) reported that the highly plastic characteristic of this family is associated with high base saturation, especially magnesium. It is friable when moist, slightly sticky and effervescences violently with H_2O_2. Matsusaka and Sherman (1950) showed that this soil has a low buffering capacity. Suehisa et al. (1963) indicated a high amount of manganese dioxide was a dominant characteristic of this soil group and the topsoil has 30 per cent SiO_2. Manganese toxicity has been observed on this soil in manganese-sensitive plants such as macadamia nuts, and pineapple but apparently is not serious on sugarcane. The soil of this series is primarily used for pineapple and sugarcane.

Suehisa et al. (1963) noted that the Wahiawa and Kapaa soils had a high phosphorus-fixing capacity. They attributed this primarily to the presence of high amounts of aluminum, iron and titanium as well as allophanic and halloysitic clay minerals. DeDatta et al. (1963) also found a similar phosphorus fixing capacity for Kapaa soil.

Experimental Methods

Soil Preparation and Planting

The soils were air-dried and fumigated with methyl bromide gas at the rate of 2 pounds per 100 cubic feet of enclosed space. After application of methyl bromide the soils were left covered for 48 hours and then aerated for 4

days before use. Soil pH was determined in 1:1 soil:water mixture using a glass electrode. The ingredients were stirred until a good mixture was attained and allowed to stand with occasional stirring for 30 minutes. Reading was obtained in a glass electrode, pH of 5.0 and 6.3 for Kapaa and Wahiawa, respectively.

The lime requirement of the soils was determined by addition of $CaCO_3$ at several rates and plotting a titration curve after the method of Matsusaka and Sherman (1950). Soil pH levels were adjusted to 5.0, 6.3, and 7.0. Wahiawa soil was acidified with 42.4g of sulphur per 40kg. of soil. The pH of the Wahiawa soil was raised to 7.0 using 17.2g of $CaCo_3$ per 40kg. of soil. The Kapaa was limed from pH 5.0 to 6.3 and 7.0 using 31.8 and 59.1g of $CaCo_3$ per 40kg. of soil. The soil of each reaction was tested and mixed separately. All soils were given a standard fertilizer application of N,P,K, Zn, and B at the rates of 130,250, 250,50, and 1.0 pounds per $2x10^6$ pounds respectively and thoroughly mixed.

To establish the amount of water requirement for each can, field capacity was determined using 4-inch plastic tubes 36 inches in length. The soils were packed into the tubes, saturated with water and allowed to drain for three days. Samples were taken and the per cent moisture was determined on an oven-dry soil basis. From these samples, it was found that air-dry Kapaa soil required 14cc/per 100g and air-dry Wahiawa soil 16cc/100g of water to attain field

capacity. Each 1.5 gallon container was labeled to keep accurate record of the experiment and 2.5kg. of Kapaa or Wahiawa soil was placed in each of 72 cans, respectively. The plants at the start were measured by taking stem diameter, number of branches, total height and weight of each seedling were recorded and placed in a saran house under plastic shade at the Manoa campus nursery area on March 26, 1964. The containers were placed on pans to catch nutrients which may have been leached. For nitrogen fertiliser 1000 ppm Urea was added at frequent intervals. Insects and mites were kept under control.

Due to inadequate light in the saran house, the plants were moved out into full sun on September 13, 1964. No attempt was made to protect the plants from the natural rainfall.

Growth Determinations

To determine new growth of the seedlings, total shoot length, stem diameter, fresh weight, and number of branches were taken and the original values were subtracted from them.

Sampling and Leaf Analyses

1) Leaf Sampling. In leaf analysis, the position and age of the leaf that is sampled is very important in arriving at a sound evaluation. Differences due to method of leaf sampling are great as found by many workers. The two important facts as reported by Embleton *et al*. (1962) are: (1) a well defined sampling technique must be used, and (2) in interpretation tentative standards must be used for the

sampling technique.

Full expanded leaves were taken for chemical analysis from the 2nd, 3rd, and 4th leaves from the tip. Leaf samples from the eight replications of each treatment were combined to make adequate quantities of materials for analysis. Approximately 70 leaves were used per sample. It was realized that such samples might not be typical for all treatments, but it did eliminate the possibility of differences in leaf maturity. This leaf sampling procedure was adequate for the investigation of citrus (Chapman and Pratt 1961).

2) Leaf washing and drying. Five polyethylene dishes were placed side by side and the first contained 750 ml. of a 0.1 per cent Dreft (Dodecyl Benzene Sulfonate 19.0% and Trichlorocarbanilide 0.5%) detergent solution and the second, third and fourth dishes each had 750 ml. of distilled water. The fifth dish was used to collect the wet leaves which were drained completely and placed in paper bags. The bags were dried in an oven at 65°C for 48 hours. The dried samples were crushed by hand to avoid contamination with minor elements for the iron and manganese determinations. The samples were placed in clean capped plastic bottles using the Steyn (1957) method as described by Chapman and Pratt (1961).

3) Leaf Analysis. The use of leaf analysis has attained considerable prominence as a diagnostic tool in the field of fruit tree nutrition. The 2g samples of oven dry leaf

material were placed in porcelain crucibles and ignited in a muffle furnace at 525°C for about 15 hours. The ashed samples were allowed to cool before dissolving in 20ml volumetric flasks and brought to volume. Aliquots were taken for the following determinations:

a) Phosphorous Determination. A 10ml aliquot was used for the colormetric determination with the vanadomolyodo-phosphoric yellow color method with a slight modification as given by Jackson (1958) and Chapman and Pratt (1961). The intensity of color was read at a wave length of 470 mμ on a common junior spectrophotometer which contained a blue filter. Per cent total phosphorous in leaf tissue was determined as follows: multiplying the reading of color intensity (OD) (minus the reading for the blank) by factors of standard solution (CF), total dilution (TDF) of sample and moisture (MF).

$$ppm = \frac{OD \times CF \times TDF \times MF}{}$$

b) Aluminum Determination. A 5 ml aliquot was transferred to a 50 ml volumetric flask and determined colormetrically as described by Chapman and Pratt (1961). To prevent the interference of iron (ferric state) in the formation of the aluminum complex, 1 ml of 1:100 thioglycollic acid solution was added. The thioglycollic acid reacts to form a colorless complex with iron and effectively prevents interference if the ratio of iron to aluminum does not exceed 20:1. Then 10 ml aluminum reagent was added and brought to about 40 ml with distilled water. The solution

was adjusted to pH 4.2 with 1:1 NH_4OH and immersed in boiling water for 16 minutes. The volumetric flasks were removed from the water bath, cooled for one and one-half hours, made up to volume and mixed thoroughly. The intensity of the solutions was determined at 465 mμ wave length on a common junior spectrophometer. Parts per million aluminum in leaf tissue was calculated using the formula given above for phosphorous.

c) Calcium Determination. A 10 ml aliquot was transferred to a porcelain dish and determined with Ethylenediaminetetraacetate (EDTA) as described by the U.S. Salinity Laboratory (1954), USDA Handbook 60. The solution was diluted to a volume of approximately 25 ml with distilled water. About 11 to 15 drops of 4 N sodium hydroxide and approximately 50 mg ammonium purpurate indicator were added and the mixture was titrated with EDTA (0.0107N). The per cent calcium was calculated as follows:

$$\% = \frac{\text{EDTA (ml)} \times \text{EDTA (N)} \times \text{TDF} \times \text{MF}}{}$$

d) Iron Determination. A 5 ml aliquot was transferred to a 50 ml volumetric flask and the iron was determined colormetrically by the Ortho-phenanthroline method. An orange-red complex is formed when Ortho-phenanthroline reacts with ferrous iron. The color intensity is dependent on acidity over a pH range from 2.0 to 9.0; but to avoid interference the pH was buffered with sodium citrate at pH 3.5. The colored complex is stable for several months.

The method followed here was from Chapman and Pratt (1961) adapted from Sandell (1950). To the aliquot 1 ml each of hydroquinone and 0.5 per cent Ortho-phenanthroline solutions and 2 ml of sodium citrate solution were added. They were then made to volume and allowed to stand 1 hour at room temperature (above 22°C) to insure complete reduction of iron. The color intensity of the solution was determined at a wave length of 508 mu. The parts per million of iron in leaf tissue was calculated using the formula given above for phosphorous.

e) Manganese Determination. A 10 ml aliquot was used for determination. Manganese was determined colormetrically by potassium periodate method as outlined by Kacar (1962). The intensity of the permanganate color is used as a quantitative estimate of the amount of manganese present. Phosphoric acid was included to avoid precipitation of ferric periodate, to decolorize iron by complex formation, and to prevent precipitation of either periodates or iodates of manganese. Five ml of concentrated sulfuric acid were added to the aliquot and brought to 25 ml volume with distilled water. Approximately 0.3g potassium periodate was added. The mixture was brought to a gentle boil on a hot plate and maintained for about 5 minutes after the color was developed. The digest was cooled, transferred quantitatively to a 50 ml volumetric flask and brought to volume. The intensity of color was determined colormetrically on a common junior

spectrophotometer using a blue filter. The manganese content was determined as described for iron.

4) Cation-exchange Capacity of Roots. Tests were made to compare the relative activity of different root systems. Duplicate samples were taken from each treatment which consisted of roots from 3 pots for each sample. In sampling the pots were washed to remove the soil from the root surface and 1 to 2 inch-long fresh root tips were taken for analysis.

Prior to analysis for cation-exchange capacity, root samples were first washed thoroughly with tap water and then with distilled water. A 300 ml of 0.01 N HCl were added to three beakers and 200 ml of distilled water to each of two beakers. Root samples were soaked for one minute in each of the first three beakers then drained and transferred to the distilled water beaker for 5 seconds and titrated with 0.01 N KOH solution. The pH of root suspension was determined by the addition of 0.1 N KOH up to neutral point. This root suspension was allowed to neutralise for 5 minutes. The roots were drained thoroughly and dried in an oven at 65°C for 48 hours. From this, root cation-exchange capacity in me/100g of dry weight basis was determined. The method was adapted from Heintze (1961).

5) Cation-exchange capacity and extractable Cations in Soils.

a) Soil preparation. Two samples from each of the original soils were taken for determination of cation-exchange

capacity and extractable cations. The pH was determined on duplicate samples for each treatment.

b) Cation-exchange capacity of soil. Twenty grams of air-dry soil were placed in 500 ml Erlenmeyer flasks and 100 ml of neutral N ammonium acetate was added. The flasks were shaken for an hour on a mechanical shaker and allowed to stand overnight. The suspension was filtered through a Buchner funnel under suction and washed with 100 ml of extractant and 200 mls of 95-98 per cent alcohol. (Leachate was saved for extractable cations determination).

The soil including filter paper was transferred to 500 ml Erlenmeyer flasks and 100 ml of 4 per cent KOH was added. The flask was shaken for 30 minutes and allowed to stand for 5 hours. It was then filtered through a Buchner funnel under suction and washed 4 times with 25 ml of 4 per cent KCl; the filtrate was transferred into 800 ml Kjeldahl flasks and 1 tablespoon MgO was added. It was stoppered, shakened and then distilled into a 350 ml Erlenmeyer flask containing 50 ml 4 per cent boric acid and 3 to 5 drops of mixed (methyl red and methyl blue) indicator. The extract was distilled and the distillate was titrated with standard 0.1073 N sulfuric acid.

c) Extractable calcium and magnesium. Fifty milliliters of the original filtrate were evaporated to dryness and digested with 5 ml of 6 N nitric acid for 30 minutes on a hot plate. The beakers were covered with a watch glass

during digestion. The digest was evaporated to dryness and diluted with 50 ml of distilled water for calcium and magnesium determination. Extractable calcium was determined by titration with 0.0107 N EDTA as described by Diehl et al. (1950) under plant analysis procedure.

Magnesium determination was made using Eriochrom Black-T indicator and titrated with 0.01 N EDTA as described for calcium determination.

d) Extractable potassium and sodium. Potassium and sodium were determined in a Beckman DU flame photometer at 769 and 869 mμ wave length, respectively. Since the intensity of light emitted by each element depends primarily on the concentration of its atoms in the flame at any given instant, a measurement of the intensity of the emitted light characteristic of a given element makes possible the quantitative determination of that element. The potassium and sodium concentration was determined from a graph obtained by the use of different standards and expressed in me per 100g oven-dried basis.

e) Extractable aluminum: The extractable aluminum was determined by extracting the soil with barium chloride and ammonium acetate-barium chloride solution buffered to pH 4.8. A 10g sample of air dried soil was placed in a 150 ml beaker and 50 ml of extracting solution of either 1 N $BaCl_2$ or 1 N NH_4OAC mixture of 0.2 N $BaCl_2$ was added and allowed to stand overnight.

The samples were then filtered through Whatman filter paper No. 42 and washed with a 10 ml portion of extracting solution. The filtrates were transferred and diluted to 100 ml.

Aluminum, extracted with two extractants $BaCl_2$ and NH_4OAc-$BaCl_2$ mixture, was determined using aluminum and adding thioglycollic acid as an agent to prevent interference by iron as described by Chenery (1948).

f) Extractable manganese: Ten grams of air dried soil, 0.25g carbon black and 50 ml of extracting solution (Morgan's Solution) were added to a 250 ml Erlenmeyer flask and shaken for 30 minutes. The suspension was filtered with No. 42 Whatman filter paper on a suctioning apparatus employing a Buchner funnel. Fifteen milliliters of the extract and 15 ml of phosphoric acid were transferred to a 50 ml volumeric flask and shaken. Six milliliters of potassium periodate solution was added to the mixture and shaken. It was brought to volume with the extracting solution and the color intensity was read at a wave length of 525 mμ on a common junior spectrophotometer using a blue filter. The concentration of exchangeable manganese in the soil was calculated using the formula given above for phosphorous.

6) Soil pH: To determine the final pH of the treatments, samples were taken from 6 pots of each treatment. The soil of 3 pots was composited and soil pH was determined in 1:1 soil water mixture as described by Chapman and Pratt (1961).

One hundred milliliters of water were added to 100g of soil in a 250 ml beaker. The paste was allowed to stand with occasional stirring for 30 minutes, and then the pH was determined with an electrode immersed in the paste.

Experiment 2. Effect of photoperiod on growth increase of Cleopatra mandarin, Troyer citrange and Trifoliate orange

The objective of the second set of experiments was to determine if short daylength contributed to the poor growth of Trifoliate rootstock in Hawaii. Hawaii is located at 21 degrees N latitude in comparison to much longer days at 33 to 40 degrees N in Japan and California where Trifoliate is used commercially as a rootstock for tangerines and oranges.

A preliminary study in a growth chamber indicated growth differences favoring longer days. The experiment was terminated because of low light intensity (200-600 ft.-candles) and soil problems.

In the second experiment, a split-plot design was used with 3 photoperiods as main plots. The three seedling types were replicated 8 times within the main plots resulting in a total of 72 plants. The experiment was conducted in the nursery with ambient temperature using 8 month old seedlings of Troyer citrange, Cleopatra mandarin and Rubidoux Trifoliate planted in 46 oz. cans in a uniform steam pasturized potting mix which consisted of half compost and half top soil.

The experiment was initiated on November 11th with a

normal day of 11 hours and 10 minutes. The daylength decreased to 10 hours and 50 minutes December 21st and then increased to 12 hours in March when the final measurements were made. The temperature extremes during this period were between 62 and 84°F. The mean monthly maximum and minimum temperatures ranged between 77.4 to 79.6 and 68.8 to 70.9°F, respectively. The nursery area is intermittently cloudy with frequent light showers.

The normal and long day photoperiod treatments were placed side-by-side separated by a light proof wall. The long photoperiod treatment received the normal day plus 4 hours of supplemental light from 10:00 P.M. to 2:00 A.M. The source of light consisted of 4 one hundred watt incandescent lamps having an intensity of 80-100 foot candles at plant level. The short day treatment received 8 hours of normal day light followed by 16 hours of darkness. Except for the light variable, all of the treatments received the same cultural practices.

RESULTS AND DISCUSSION

Experiment 1. The growth of citrus rootstock seedlings on two Hawaiian soils at three pH levels.

This study involved the effect of two soil types at three pH levels on the growth of three rootstocks used for the propagation of oranges. In this study an attempt was made to determine the reason for poor seedling growth of Trifoliate orange in Hawaii. Tissue analyses of leaves and soils were made in order to ascertain the effect of aluminum and manganese on the absorption of iron, calcium and phosphorus in the seedling rootstocks.

Growth Data

The results describing the change in stem diameter, shoot length, fresh weight and number of branches taken from the rootstock seedlings are given in Tables 1 to 4. The range of increases in growth for the rootstocks studied for a period of one year was 1 to 60 mm for stem diameter, 55 to 340 cm for shoot length, 10 to 163 g for fresh weight and 0 to 9 for number of branches. Large differences were found at different pH levels and among rootstocks and soils. The data represented results for the period of one year starting March 1964.

Statistical analyses for each growth factor investigated were made and the results of the analysis of variance are shown in Appendix Tables 1 and 2.

The analysis of variance shows that there was a highly significant difference in new growth for treatments, soils, soil pH and soils x rootstocks for all growth measurements. The interaction of rootstock seedlings to soil was highly significant for the growth measurements of only the shoot length and stem diameter.

TABLE 1. INCREASES IN STEM DIAMETER OF THREE ROOTSTOCKS ON TWO SOIL TYPES AT THREE pH LEVELS [a]

Diameter Increase - Millimeters

	Wahiawa pH			Kapaa pH		
Rootstock	5.0	6.3	7.0	5.0	6.3	7.0
Cleopatra	4.1	38.9	30.2	37.5	53.6	48.1
Trifoliate	2.3	16.3	14.4	6.4	14.3	14.3
Troyer	5.0	21.0	33.9	3.7	34.5	38.6

[a] Each treatment mean represents eight replications.

TABLE 2. INCREASE IN SHOOT LENGTH OF THREE ROOTSTOCKS ON TWO SOIL TYPES AT THREE pH LEVELS [a]

Shoot Length Increase-centimeters

	Wahiawa pH			Kapaa pH		
Rootstock	5.0	6.3	7.0	5.0	6.3	7.0
Cleopatra	43.9	167.0	167.8	196.4	309.7	297.7
Trifoliate	9.0	53.4	64.1	18.4	79.3	71.0
Troyer	20.6	123.6	133.8	94.1	161.3	222.9

[a] Each treatment mean represents eight replications.

TABLE 3. INCREASE IN NUMBER OF BRANCHES OF THREE ROOTSTOCKS ON TWO SOIL TYPES AT THREE pH LEVELS [a]

Increase in Number of Branches

	Wahiawa pH			Kapaa pH		
Rootstock	5.0	6.3	7.0	5.0	6.3	7.0
Cleopatra	3.4	5.1	5.9	4.8	7.4	7.1
Trifoliate	3.0	4.4	3.4	1.1	4.4	3.1
Troyer	2.1	6.0	5.3	3.1	5.9	5.3

[a] Each treatment mean represents eight replications.

TABLE 4. INCREASE IN FRESH WEIGHT OF THREE ROOTSTOCKS ON ON TWO SOIL TYPES AT THREE pH LEVELS [a]

Weight Increase Grams/Plant

	Wahiawa pH			Kapaa pH		
Rootstock	5.0	6.3	7.0	5.0	6.3	7.0
Cleopatra	30.2	134.6	185.2	246.7	399.1	563.0
Trifoliate	11.5	23.0	38.1	20.4	27.3	39.5
Troyer	21.7	84.0	142.1	27.3	149.3	161.8

[a] Each treatment mean represents three replications.

The discussion of the growth data will be confined to stem diameter and fresh weight throughout this thesis because the statistical analyses for stem diameter, shoot length, number of branches and fresh weight were essentially identical, and stem diameter growth is commonly used in treecrops as a measure of total tree growth. The Duncan Multiple

Range Test was employed for the stem diameter and fresh weight data.

Rootstocks. Of the three rootstocks, Cleopatra made the largest growth increases, Troyer intermediate and Trifoliate the least. Cleopatra had an increase in diameter of 35 mm (68%) and 62 g (89%) in fresh weight over Troyer and Trifoliate respectively. These differences are shown in Table 5 and Fig. 1 to 3.

TABLE 5. GROWTH OF ROOTSTOCKS FOR ALL TREATMENTS

Rootstock	Stem Diameter Growth mm/plant	Increase in Fresh Weight g/plant
Cleopatra	35.0_a	259.7_a
Troyer	23.3_b	97.6_b
Trifoliate	11.3_c	26.6_c

Means followed by different letters are statistically different at the 1% level as indicated by Duncan's Multiple Range Test.

Cleopatra was in leaf and growing at the start of the experiment; Troyer and Trifoliate were dormant and the latter had few leaves. This disadvantage at the start of the experiment may account for some of the growth differences observed.

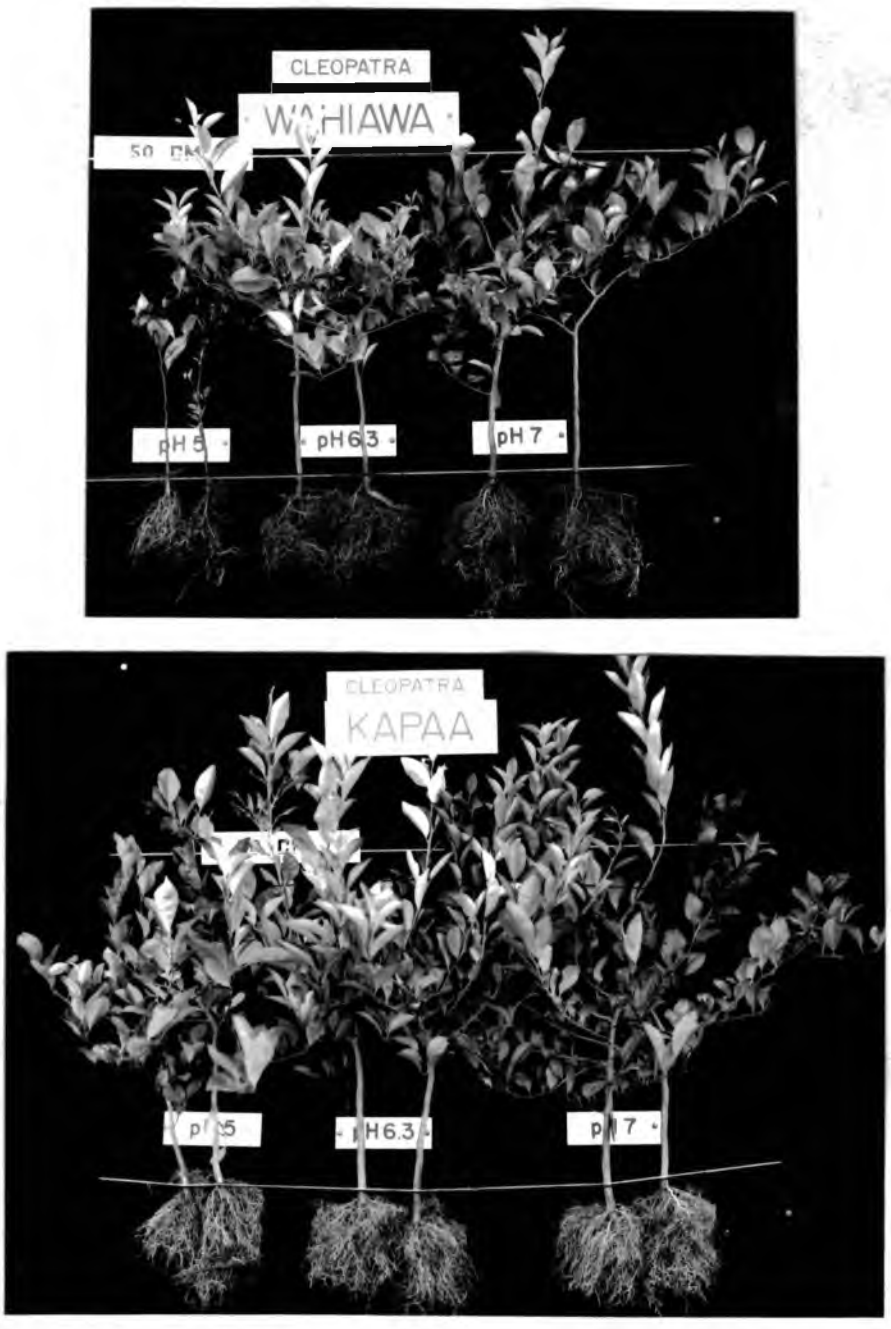

FIG. 1. GROWTH OF CLEOPATRA MANDARIN IN KAPAA AND WAHIAWA SOILS AT 3 pH LEVELS

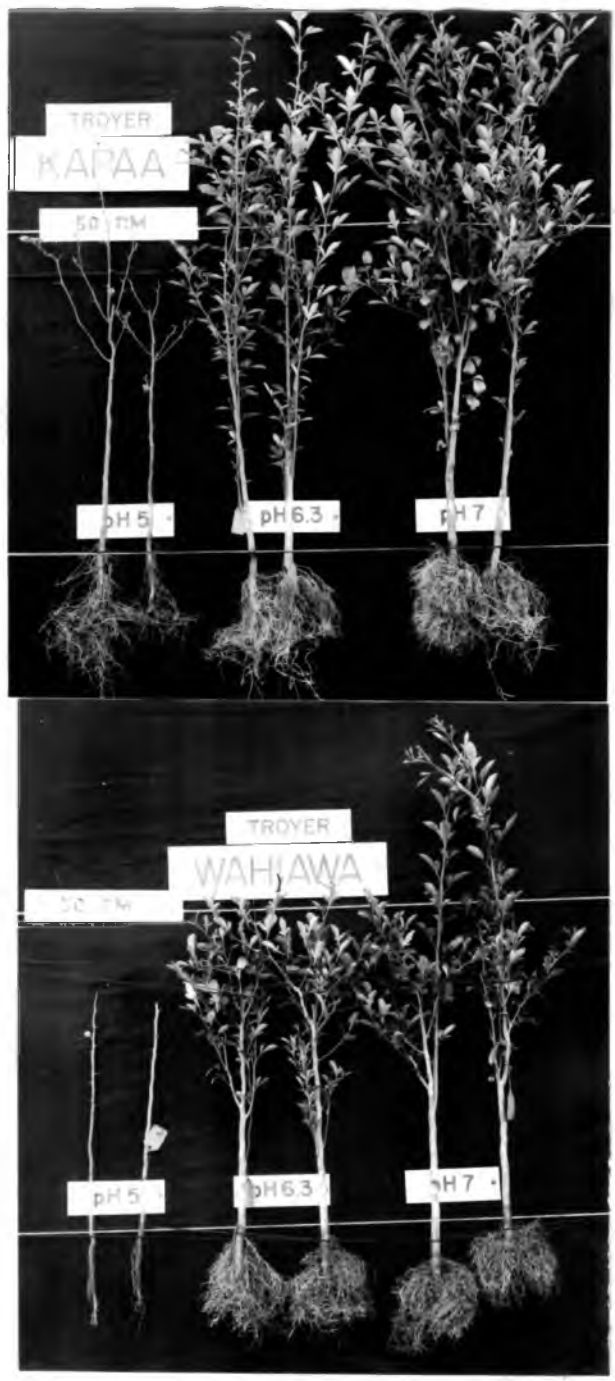

FIG. 2. THE GROWTH OF TROYER CITRANGE IN KAPAA AND WAHIAWA SOILS AT 3 pH LEVELS

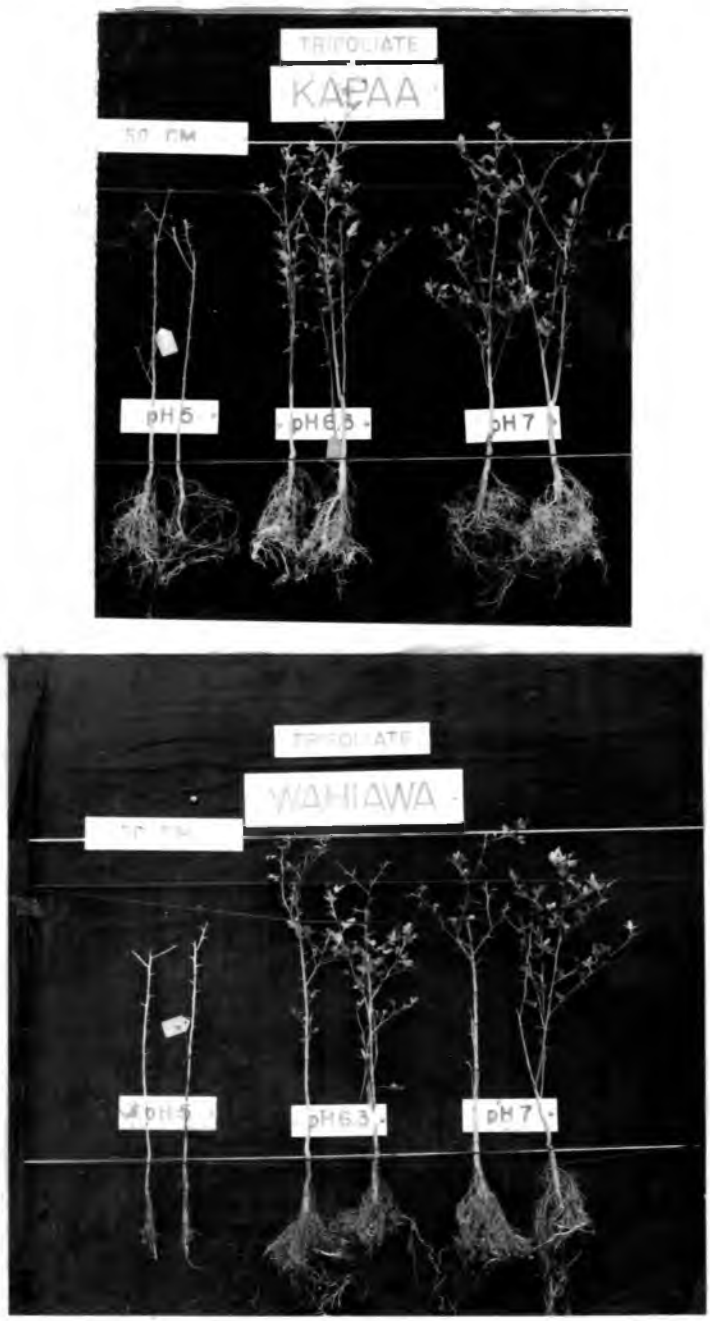

FIG. 3. THE GROWTH OF TRIFOLIATE ORANGE IN KAPAA AND WAHIAWA SOILS AT 3 pH LEVELS

Effect of soil on growth of rootstock seedlings. To compare the growth of Cleopatra, Troyer and Trifoliate two soils were used in the experiment. The increase in stem diameter and plant fresh weight were greater in Kapaa than in Wahiawa soil. Increases of 35 and 55 per cent were found with the Kapaa over Wahiawa soil for stem diameter and fresh weight, respectively. The differences are shown in Table 6 and Fig. 1 to 3.

TABLE 6. EFFECT OF SOIL ON GROWTH OF CITRUS ROOTSTOCK SEEDLINGS

Soil	Diameter Increase mm/plant	Fresh Weight Increase grams/plant
Kapaa	41.8_a	181.6_a
Wahiawa	27.7_b	74.5_b

Means followed by different letters are statistically different at the 1% level using Duncan's Multiple Range Test.

Effect of pH on growth of citrus rootstock seedlings. Three pH levels of the soil were studied to determine its effect on stem diameter and plant fresh weight increase. Results show that the 6.3 and 7.0 pH levels were more satisfactory for plant growth than a pH of 5.0 (Table 7). There were no statistically significant differences between pH 6.3 and 7.0. Increases of 66% for stem diameter and 64-68% for fresh weight were found between the high and low pH levels.

TABLE 7. EFFECT OF SOIL pH ON GROWTH OF CITRUS ROOTSTOCK SEEDLINGS

pH	Diameter mm/plant	Fresh Weight grams/plant
7.0	29.9_a	188.2_a
6.3	29.6_a	167.6_a
5.0	9.8_b	59.6_b

Means followed by different letters are statistically different at the 1% level as measured by Duncan's Multiple Range Test.

The decrease in growth for the treatments at pH 5.0 may not have been solely the result of H-ions. Martin and Page (1962) found good growth of citrus seedlings at pH levels ranging from 4.0 to 8.5.

Interaction between soil and rootstock seedlings. The growth of all three rootstocks was greater on Kapaa than on Wahiawa soil, but Trifoliate was only slightly so. These interactions were calculated for stem diameter and fresh weight increases as shown in Table 8 and are shown graphically in Fig. 4.

Mean increases of stem diameter and fresh weights of Cleopatra seedlings grown on Kapaa soil were 65% higher than Trifoliate and 33% higher than Troyer seedlings. Similarly, Cleopatra seedlings grown in Kapaa soil had stem diameters which were 48% greater than in Wahiawa soil. However, Cleopatra growth in Wahiawa soil was not significantly greater than Troyer. The growth difference

TABLE 8. INTERACTION OF SOIL AND ROOTSTOCK ON INCREASES IN STEM DIAMETER AND FRESH WEIGHT OF CITRUS ROOTSTOCKS

Treatments Rootstocks	Soil*	Stem Diameter Increases mm/plant	Fresh Weight Increases grams/plant
Cleo.	K.	46.4_{a}	402.9_{a}
Troy.	K.	25.6_{b}	112.8_{b}
Cleo.	W.	24.4_{bc}	116.6_{bc}
Troy.	W.	20.0_{bc}	82.6_{bc}
Trif.	K.	12.7_{bc}	29.0_{bc}
Trif.	W.	11.0_{c}	24.2_{c}

Means followed by different letters are statistically different at the 1% level as measured by Duncan's Multiple Range Test.
*Note: K-Kapaa, W-Wahiawa

between Troyer and Trifoliate was about 55% irrespective of soil. Cleopatra and Troyer had a more dense root systems than Trifoliate in both soils studied. Growth of Trifoliate orange seedlings was not statistically different in the two soils studied. This shows that Trifoliate orange did not grow satisfactorily in these two soils.

Interaction between rootstock seedlings and pH. There was a highly significant difference between the growth of rootstock seedlings and soil pH. Trifoliate orange seedlings exhibited the least amount of growth at all pH levels and Cleopatra the most. Similarly, the increase in growth stem diameter of Cleopatra at pH 7.0 was not statistically different than Troyer grown at pH 6.3. These differences

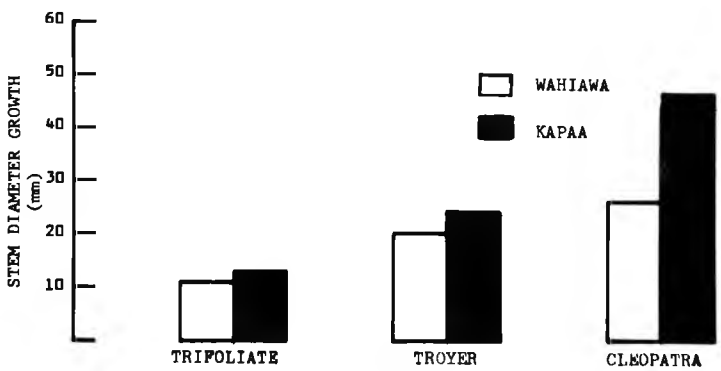

FIG. 4. INTERACTIONS OF SOILS AND ROOTSTOCKS ON STEM DIAMETER GROWTH

are shown in Table 9.

TABLE 9. INTERACTION OF ROOTSTOCK SEEDLINGS AND pH

Treatments		Stem Diameter Increases	Treatments		Fresh Weight Increases
Rootstocks	pH	mm/plant	Rootstocks	pH	grams/plant
Cleo.	6.3	46.3 a	Cleo.	7.0	374.1 a
Cleo.	7.0	39.2 b	Cleo.	6.3	266.8 b
Troy.	7.0	36.3 b	Troy.	7.0	151.9 c
Troy.	6.3	27.8 c	Cleo.	5.0	138.4 c
Cleo.	5.0	20.8 d	Troy.	6.3	116.6 cd
Trif.	6.3	15.4 e	Trif.	7.0	38.8 de
Trif.	7.0	14.4 e	Trif.	6.3	25.1 e
Troy.	5.0	14.4 e	Troy.	5.0	24.9 e
Trif.	5.0	4.4 f	Trif.	5.0	15.9 e

Means followed by different letters are statistically different at the 1% level as measured by Duncan's Multiple Range Test.

The results show that the stem diameter of Cleopatra at pH 6.3 was significantly greater than at pH 7.0; whereas the opposite results were obtained for fresh weight. Aside from this exception, the investigation shows that pH 6.3 and 7.0 are satisfactory for growth of the species studied. A pH of 5.0 was more injurious to Trifoliate orange than the other two species.

Interaction between soil, pH and rootstock. This investigation shows that the soil, soil pH and the rootstocks

studied were correlated. The increase of stem diameter of Cleopatra grown on Kapaa soil was significantly higher than the remaining treatments.

A difference in growth of Troyer over Trifoliate was found. The growth difference of Troyer on Kapaa soil at pH 6.3 and pH 7.0 was comparable with Cleopatra on Wahiawa soil at pH 7.0. Cleopatra was superior in both soils as compared to Trifoliate and to some extent to Troyer rootstock seedlings. These differences are reported in Table 10 and shown graphically in Fig. 5.

Growth increase of Cleopatra at pH 6.3 and 7.0 on Kapaa soil was significantly higher than Wahiawa soil. The increment of stem diameter was higher at pH 6.3 while the fresh weight was highest at pH 7.0. Conversely, Trifoliate in Wahiawa soil at pH 5.0 was statistically lower than the other treatments. The fresh weight increment at pH 7.0 of Cleopatra on Kapaa soil was fifty times higher than Trifoliate grown on Wahiawa soil pH 5.0.

Soil Analysis

An attempt was made to determine why plants in Kapaa soil had a larger stem diameter and fresh weight increase than in Wahiawa soil. Soil samples were analyzed for potassium, sodium, calcium, magnesium, aluminum and manganese. Duplicate determinations for aluminum, calcium, manganese, magnesium, potassium, sodium, Cation Exchange Capacity (CEC) and pH from each of the original soils were

TABLE 10. INTERACTION OF ROOTSTOCK, pH AND SOILS ON INCREASE OF STEM DIAMETER AND FRESH WEIGHT

TREATMENTS			Stem Diameter Increases mm/plant	TREATMENTS			Fresh Weight Increases g/plant
Rootstock	Soil*	pH		Rootstock	Soil*	pH	
Cleo.	K.	6.3	53.6 a	Cleo.	K.	7.0	563.0 a
Cleo.	K.	7.0	48.1 b	Cleo.	K.	6.3	399.1 b
Cleo.	W.	6.3	38.9 c	Cleo.	K.	5.0	246.7 c
Troy.	K.	7.0	38.6 c	Cleo.	W.	7.0	185.2 cd
Cleo.	K.	5.0	37.5 cd	Troy.	K.	7.0	161.8 d
Troy.	K.	6.3	34.5 d	Troy.	K.	6.3	149.3 d
Troy.	W.	7.0	33.9 de	Troy.	W.	7.0	142.1 d
Cleo.	W.	7.0	30.2 e	Cleo.	W.	6.3	134.6 de
Troy.	W.	6.3	21.0 f	Troy.	W.	6.3	84.0 ef
Trif.	W.	6.3	16.3 g	Trif.	K.	7.0	39.5 f
Trif.	W.	7.0	14.4 g	Trif.	W.	7.0	38.1 f
Trif.	K.	6.3	14.3 g	Cleo.	W.	5.0	30.2 f
Trif.	K.	7.0	14.3 g	Troy.	K.	5.0	27.3 f
Trif.	K.	5.0	6.4 h	Trif.	K.	6.3	27.3 f
Troy.	W.	5.0	5.0 h	Trif.	W.	6.3	23.0 f
Cleo.	W.	5.0	4.1 h	Troy.	W.	5.0	21.7 f
Troy.	K.	5.0	3.7 h	Trif.	K.	5.0	20.4 f
Trif.	W.	5.0	2.3 h	Trif.	W.	5.0	11.5 f

Means followed by different letters are statistically different at the 1% level as measured by Duncan's Multiple Range Test.
*K-Kapaa, W-Wahiawa.

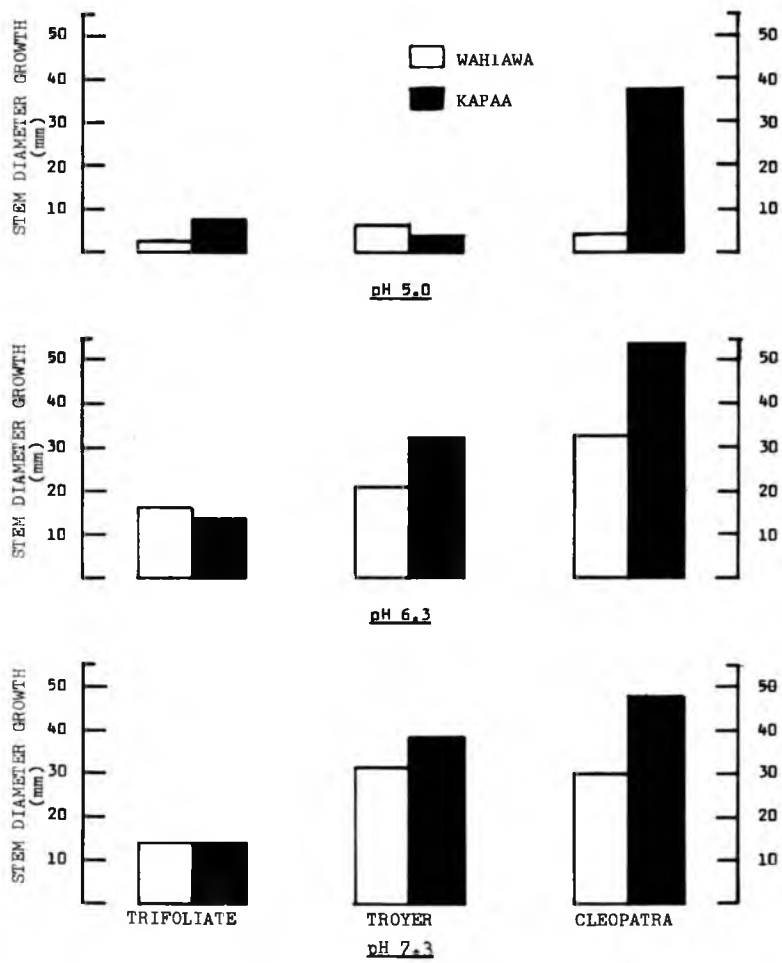

FIG. 5. INTERACTIONS OF ROOTSTOCKS, SOILS AND SOIL pH ON STEM DIAMETER GROWTH

made. Results for two soils are given in Table 11.

TABLE 11. RESULTS OF SOILS ANALYSES FOR EXCHANGEABLE CATIONS, CATION EXCHANGE CAPACITY AND pH

	Exchangeable Cations							
	me/100g oven-dry basis							
	Ca	Mg	K	Na	Al	Mn (ppm)	CEC	pH
Kapaa	0.75	0.81	0.10	0.19	11.9	2.4	28	5.0
Wahiawa	4.47	1.01	0.15	0.19	1.56	20.9	10	6.3

The results indicate that Wahiawa soil was higher in all nutrients studied except aluminum and sodium. The highest concentration of extractable calcium, magnesium and potassium was obtained from Wahiawa soil. Both soils had the same concentration of extractable sodium. Extractable aluminum was highest in Kapaa soil.

The results of the study on the Cation-exchange capacity of the two soils are given above. The Wahiawa soil which is used extensively for sugarcane and pineapple cultivation had a lower value for cation-exchange capacity than Kapaa. This finding is in agreement with that of Kanehiro and Chung (1952). They reported 33.3 me/100g for Kapaa soil and 17.8 me/100g for Wahiawa. This low value in Hawaiian soils is associated with a high content of kaolinite. In Low Humic Latosols, there appears to be a direct relationship between buffering capacity and cation-exchange capacity. The above workers found a direct correlation between base saturation

and cation-exchange capacity. Conversely, they also showed that soil with a low base saturation and low pH can have a high cation-exchange capacity. This is true in highly weathered soil as reported by Pierre and Scorseth (1931). The Humic Ferrugious Latosol group is highly weathered and the Vanadium content is higher than Low Humic Latosol (Nakamura and Sherman 1961). This may explain why Kapaa, a highly weathered soil, has a higher cation-exchange capacity than Wahiawa.

It seems that the cation-exchange capacity of the soil is more important than the total exchangeable cations of the soil in the uptake and increase of plant growth. The result of better growth of plants on Kapaa soil tends to support the above theory. This is highly speculative but is important and warrants further investigation.

Plant Analysis

Analysis of leaf and root samples were made for phosphorus, calcium, aluminum, iron and manganese.

Aluminum, Iron and Manganese uptake. Aluminum content of Trifoliate leaves grown in Kapaa soil was slightly higher than Troyer and almost twice as much as Cleopatra (Table 12). The same trend was obtained with the Wahiawa soils. But the aluminum concentration in the leaves was approximately 50% of that obtained from the Kapaa soil. The aluminum was more soluble and the leaf content was higher at the lower pH levels for both soils.

TABLE 12. INFLUENCE OF TWO SOILS AND THREE pH LEVELS ON NUTRIENT CONCENTRATION IN LEAVES OF CITRUS ROOTSTOCKS

Soil	Rootstock	pH	P % a/	Ca % a/	Al ppm a/	Fe ppm a/	Mn ppm a/	CEC of roots me/ 100g oven-dry b/
Wahiawa (Low Humic Latosol)	Cleopatra	5.0	0.09	0.95	182	58	559	7.3
		6.3	0.17	1.31	134	48	320	16.0
		7.0	0.16	1.44	111	37	261	13.4
	Troyer	5.0	0.14	1.82	292	136	1281	10.0
		6.3	0.21	3.36	162	99	1010	15.8
		7.0	0.17	3.52	146	96	625	17.0
	Trifoliate	5.0	c/					10.8
		6.3	0.24	0.74	213	71	461	18.0
		7.0	0.24	1.41	197	58	385	22.3
Kapaa (Aluminous Humic Ferruginous Latosol)	Cleopatra	5.0	0.11	0.68	295	81	92	9.2
		6.3	0.15	1.95	259	71	67	14.0
		7.0	0.12	2.06	235	58	37	19.5
	Troyer	5.0	0.09	0.89	545	262	149	11.4
		6.3	0.21	4.02	365	218	92	17.7
		7.0	0.18	4.65	348	173	60	20.0
	Trifoliate	5.0	c/					8.3
		6.3	0.23	1.42	487	195	167	20.8
		7.0	0.22	1.47	459	185	145	20.3

a/ Mean of duplicate determinations on composite sample of eight replications after ashing.
b/ Mean of two replications.
c/ Treatment not sampled.

Iron concentration (ppm) was higher in the Troyer seedlings in the two soils. The iron concentrations (ppm) of seedlings grown in the Wahiawa soil were Troyer 110 ppm, Trifoliate 64 ppm and Cleopatra 48 ppm. The same trend was obtained for the Kapaa soils but the iron content in the leaves was almost 50% higher than the plants grown on the Wahiawa soil. The effect of pH on iron uptake seemed to be the same as aluminum. The difference in iron uptake between pH levels is not as great as that found in the aluminum uptake. Normally, the iron uptake is very low and the difference is not magnified as it is with aluminum.

Manganese concentration (ppm) of leaves was very high in the Troyer rootstock seedlings on Wahiawa soil. There was an increase of twofold over Trifoliate and almost threefold over Cleopatra. The manganese concentration of the leaf samples taken from the rootstocks grown in the Kapaa soil was very low compared to the Wahiawa soil; however, the 156 ppm Mn of Trifoliate represented an increase of 56 ppm over Troyer and about 90 ppm Mn over Cleopatra. The manganese uptake by rootstock seedlings increased in both soils at the low pH level. A 52% increase was obtained on the Wahiawa soil but only a 33% increase was found on the Kapaa soils between pH 5.0 and 7.0.

From these results, then, it can be said that the aluminum and iron concentration found in the plants of Kapaa soils were twice the concentration found in the plants grown in the Wahiawa soils. Manganese concentration in the

plants grown on Wahiawa soils were almost 85% higher than plants grown on Kapaa soils.

Calcium and Phosphorus uptake. As shown in Table 12, the phosphorus concentration of Trifoliate was the highest in both soils. However, Trifoliate had poor growth and this may have accounted for the higher phosphorus concentration. Cleopatra and Troyer were abundant in plant material; therefore, the phosphorus was distributed throughout a larger volume of plant tissue and this may have accounted for the lower concentration. The total phosphorus uptake was not presented because the initial weight of each rootstock seedling varied in moisture and size. The dry weight of the seedlings was not determined at planting time. The phosphorus concentration in the leaves of Cleopatra and Troyer was 0.14% and 0.17%, respectively. The difference in per cent of phosphorus in the two soils was small.

Phosphorus solubility and uptake depends upon the pH of the medium. The phosphorus concentration of the citrus leaves were highest at a pH level of 6.3. The trend appeared to be present in both soils.

Calcium accumulation in the citrus leaves did not have the same trend as phosphorus accumulation. It seems obvious, however, that the total uptake of phosphorus and calcium would be closely related. The analytical results of leaves taken from both soils showed 50% increase of calcium uptake in Troyer over Cleopatra and Trifoliate. The effect of pH

on calcium accumulation showed an increase of calcium accumulation with an increase in pH. An increase from 1.38 to 2.12% calcium was found from pH 5.0 to pH 7.0 in the Wahiawa soil and from 0.79 to 2.4% in Kapaa soil.

It was obvious in this investigation that the species of plants differed in sensitivity to manganese toxicity. Troyer citrange was a higher accumulator of manganese than the other species. However, the yield was comparable to Cleopatra and significantly higher than Trifoliate orange. Gerloff (1962) reported that the capacity of some plants to tolerate high manganese is associated with selective exclusion of the element and in others with unusual tissue tolerance of a high level of manganese (Lohnis 1960).

Cation-exchange capacity of roots. A study of the properties of plant root surface in relation to the uptake of nutrients has been of interest to many investigators. However, the concept of cation uptake in exchangeable form is still in question.

The mean values for the cation exchange capacities of the roots for Cleopatra, Troyer and Trifoliate are presented in Table 12. The data show that soil and soil pH influence the cation-exchange property of the roots. It was also noted that species vary in their cation-exchange capacity. The average values found were Trifoliate 16.7, Troyer 15.3 and Cleopatra 13.2 me/100g on an oven-dry basis. The difference in the CEC between the roots grown in the two soils appeared

to be the same; however, the CEC of the plant roots seemed to increase as the pH value increased. There was increase of 46% and 8% at pH 7.0 over pH 5.0 and pH 6.3, respectively.

The different levels of cation-accumulation in the leaves of all treatments indicated that some cations, aluminum, iron and manganese, followed a trend of negative correlation with cation-exchange capacity of the roots while calcium and phosphorus exhibited a positive correlation. The effect of some cations on the cation-exchange capacity supports the work of Crooke (1958). However, the correlations obtained in this experiment appeared to have no agreement with a report of Crooke and Knight (1962) that cations and trace elements are positively correlated with cation-exchange capacity of the plant roots. Hence, the cation-exchange properties of the roots did not account for the accumulation of aluminum, iron and manganese in the leaves of the plants.

Differences in cation accumulation were found between rootstock species as shown in Table 12. The results found in this investigation, 13-15 me/100g oven-dry basis, were below the 21-32 me/100g reported by Smith and Wallace (1954).

Correlation between stem diameter growth and nutrient uptake

In addition to the correlation between stem diameter growth, pH, and individual nutrients, correlations between stem diameter and two elemental ratios were made. As shown in Table 13 and Fig. 6 a significant negative correlation was found between stem diameter growth and aluminum uptake

TABLE 13. CORRELATION COEFFICIENTS CALCULATED FROM THE RELATIONSHIPS BETWEEN GROWTH OF CITRUS AND NUTRIENT CONTENT OF LEAVES

Factor	Soil	r	Significance
Stem diameter vs. ppm aluminum	Kapaa	-0.95	**
Stem diameter vs. ppm aluminum	Wahiawa	-0.89	*
Stem diameter vs. ppm manganese	Kapaa	-0.93	**
Stem diameter vs. ppm manganese	Wahiawa	-0.60	
Stem diameter vs. ratio of Ca/Mn	Kapaa	+0.59	
Stem diameter vs. ratio of Ca/Mn	Wahiawa	+0.90	**
Stem diameter vs. ratio of Ca/Al	Kapaa	+0.57	
Stem diameter vs. ratio of Ca/Al	Wahiawa	+0.52	
Stem diameter vs. ratio of P/Al	Kapaa	+0.61	
Stem diameter vs. ratio of P/Al	Wahiawa	+0.85	**
Stem diameter vs. ratio of P/Mn	Kapaa	+0.71	*
Stem diameter vs. ratio of P/Mn	Wahiawa	+0.70	*
Stem diameter vs. ratio of Fe/Mn	Kapaa	+0.10	
Stem diameter vs. ratio of Fe/Mn	Wahiawa	+0.69	*
Stem diameter vs. pH of soil	Kapaa	+0.42	
Stem diameter vs. pH of soil	Wahiawa	+0.88	**

* Significant at 5% level = 0.666
** Significant at 1% level = 0.789

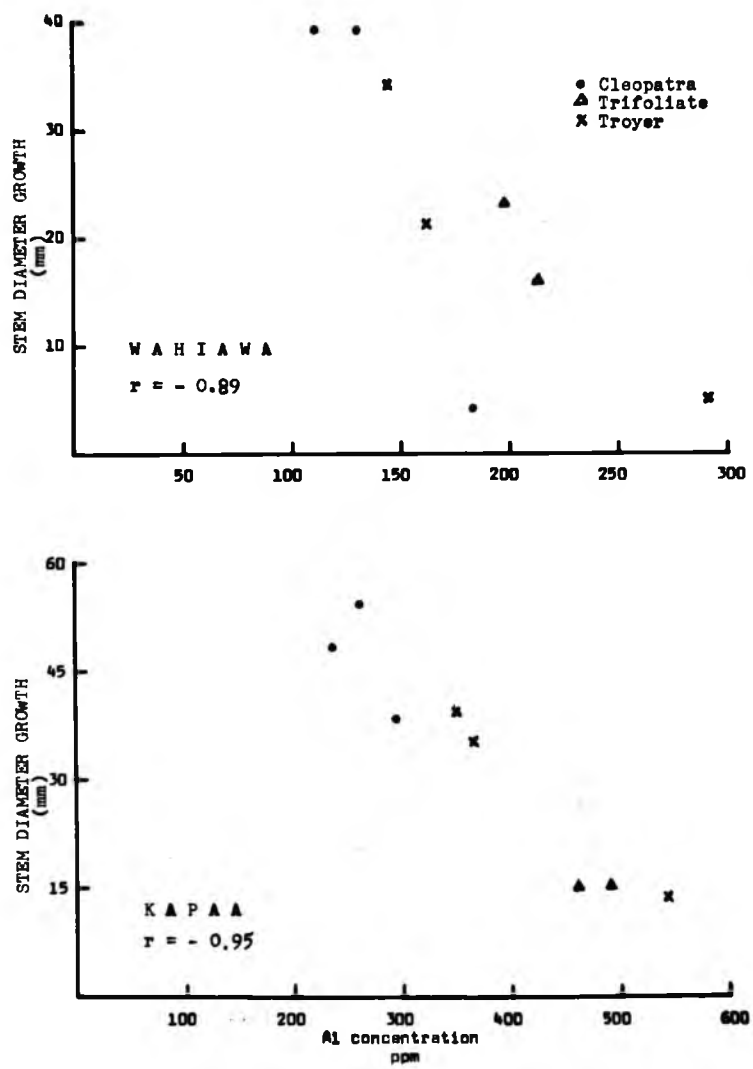

FIG. 6. RELATIONSHIPS BETWEEN GROWTH AND ALUMINUM CONTENTS OF CITRUS LEAVES

in both soils. The result of poor growth in the low Humic Latosol (Wahiawa) as compared to Aluminous Humic Ferruginous Latosol (Kapaa) may be attributed to a high manganese level in relation to iron, calcium, and phosphorus. Ratios of Fe/Mn, Ca/Mn and P/Mn were correlated with stem growth diameter. Significant differences were found among all of the ratios.

Manganese correlation with stem diameter growth (Table 13) was statistically significant with the Kapaa soil and was approaching the significant values on the Wahiawa soil. The negative correlation indicated that the stem diameter growth decreased with an increase of manganese in the plant (Fig. 7). The correlation between the ratio of Ca/Mn and stem diameter growth was statistically different only on the Wahiawa soil (Fig. 8). The Ca/Al ratio and stem diameter growth (Table 13) correlation was not significant at the 5% level for plants grown in both soils.

The P/Al ratio and stem diameter growth correlation was not significant at the 5% level for plants grown on Kapaa soil, but a highly significant negative difference was obtained for the Wahiawa soil.

The P/Mn ratio and stem diameter growth correlation was significant at the 5% level for plants grown in both soils (Fig. 9).

The Fe/Mn ratio and stem diameter growth correlation showed statistical difference with the plants grown on the

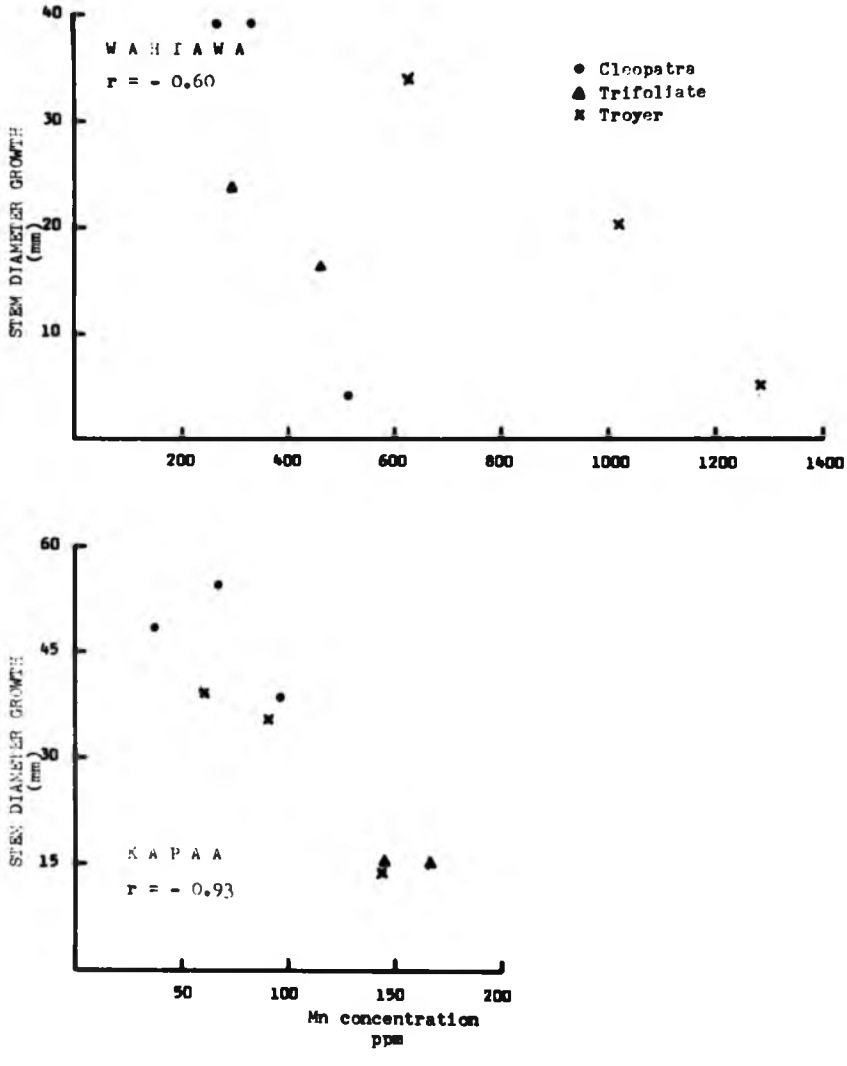

FIG. 7. RELATIONSHIPS BETWEEN GROWTH AND MANGANESE CONTENTS OF CITRUS LEAVES

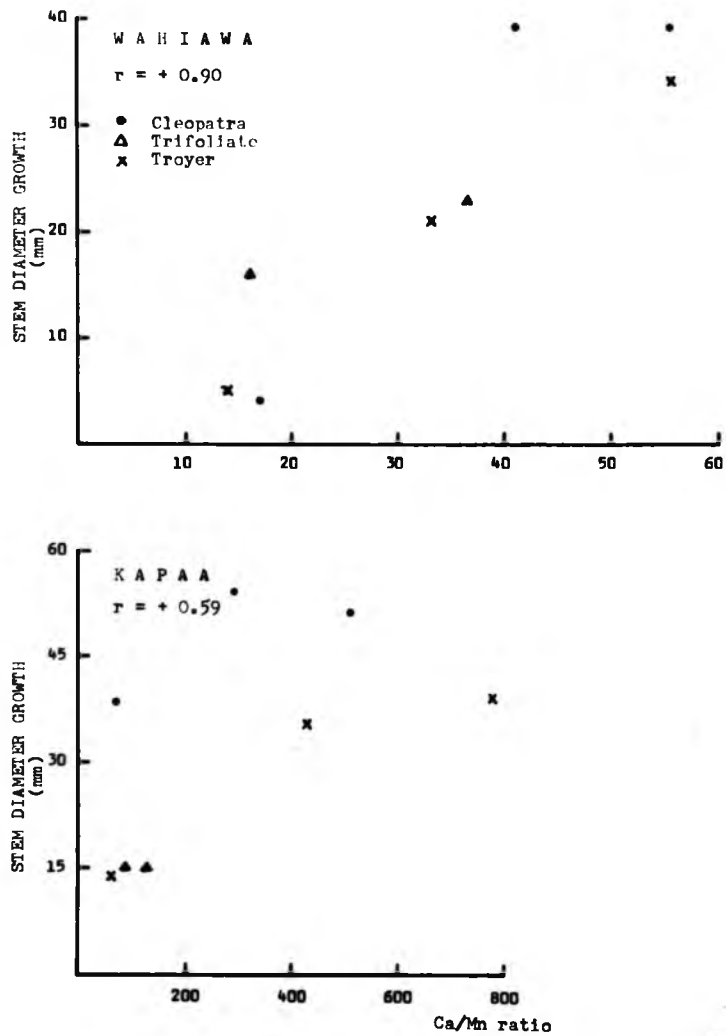

FIG. 8. RELATIONSHIPS BETWEEN GROWTH AND Ca/Mn RATIO OF CITRUS LEAVES

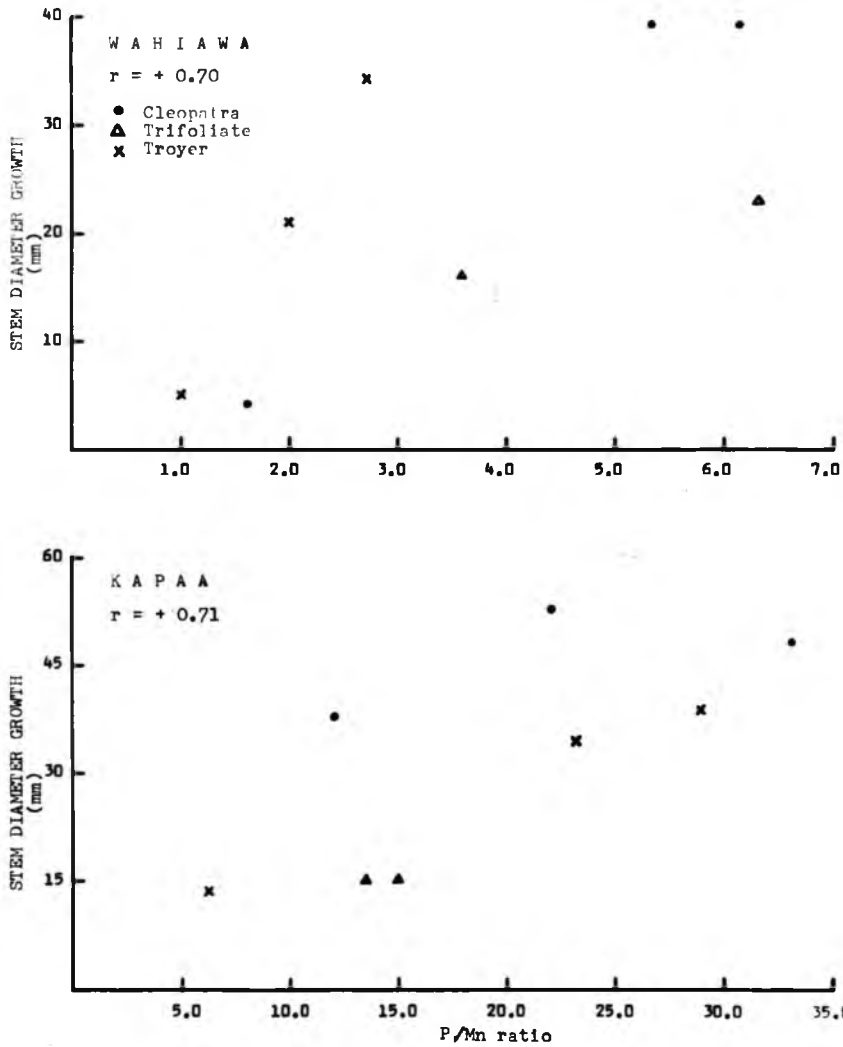

FIG. 9. RELATIONSHIPS BETWEEN GROWTH AND P/Mn RATIO OF CITRUS LEAVES

Wahiawa soil but not on the Kapaa soil (Fig. 10).

The correlation between growth and pH was highly significant in Wahiawa soil but not in Kapaa soil. This indicated that the growth was more pH dependent on Wahiawa than on Kapaa soil (Fig. 11).

The high concentration of manganese on the Wahiawa soil may have oxidized the iron to a less available form resulting in a low ratio of iron to manganese. The work of Pugliere (1913) as cited by Johnson (1924) indicated that an optimum antagonistic effect between iron and manganese was a ratio of 1:2.5 in pineapple plants. Somers and Shive (1942) suggested that a balance should exist between iron and manganese for normal plant growth. Ratios of iron to manganese obtained in this research averaged 1:8.3 for plants grown in Wahiawa soil and 1:0.65 in Kapaa soil. This means that the ratio for Wahiawa soil was too wide for normal growth, when compared with the ratio of 1:2.5 reported by Johnson. In Kapaa soil, since the ratio is less than 1:1 the plant growth was considerably better than in Wahiawa soil. Johnson (1924) reported that antagonistic effects of manganese on iron depressed the assimulation of iron by plants. He concluded that manganese dioxide, either present as such or in the form of manganese salts, would keep the iron oxidized to the much less available form. Gerloff (1963) reported that manganese antagonized the uptake of iron. The existence of mutual antagonism of manganese and

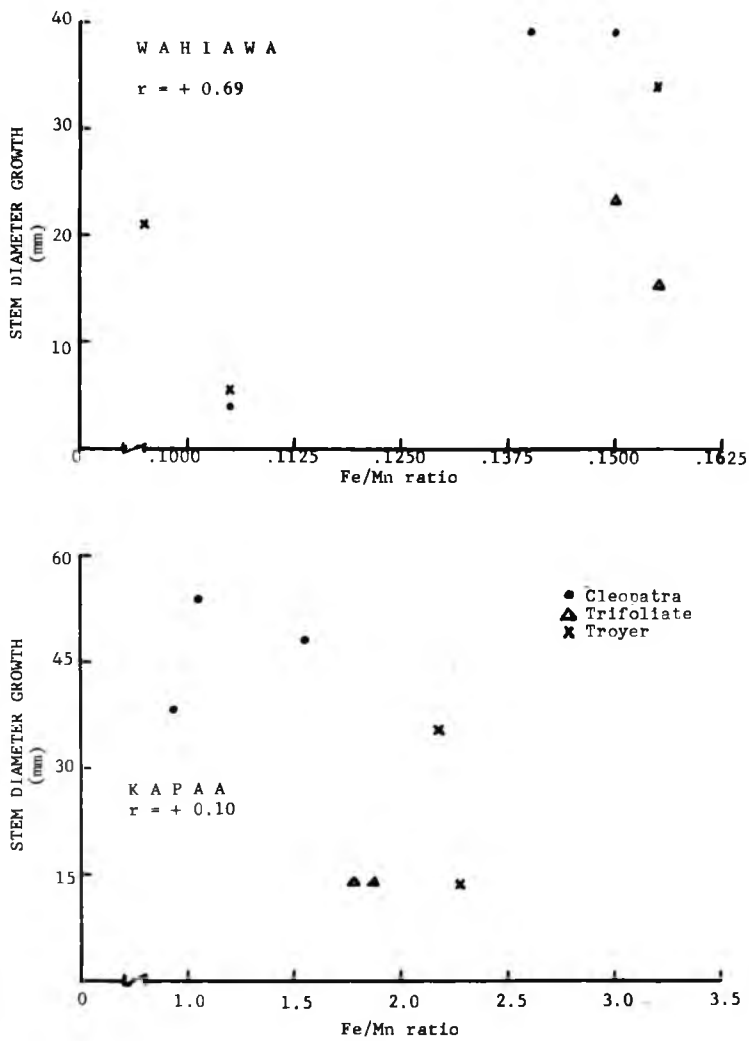

FIG. 10. RELATIONSHIPS BETWEEN GROWTH AND Fe/Mn RATIO OF CITRUS LEAVES

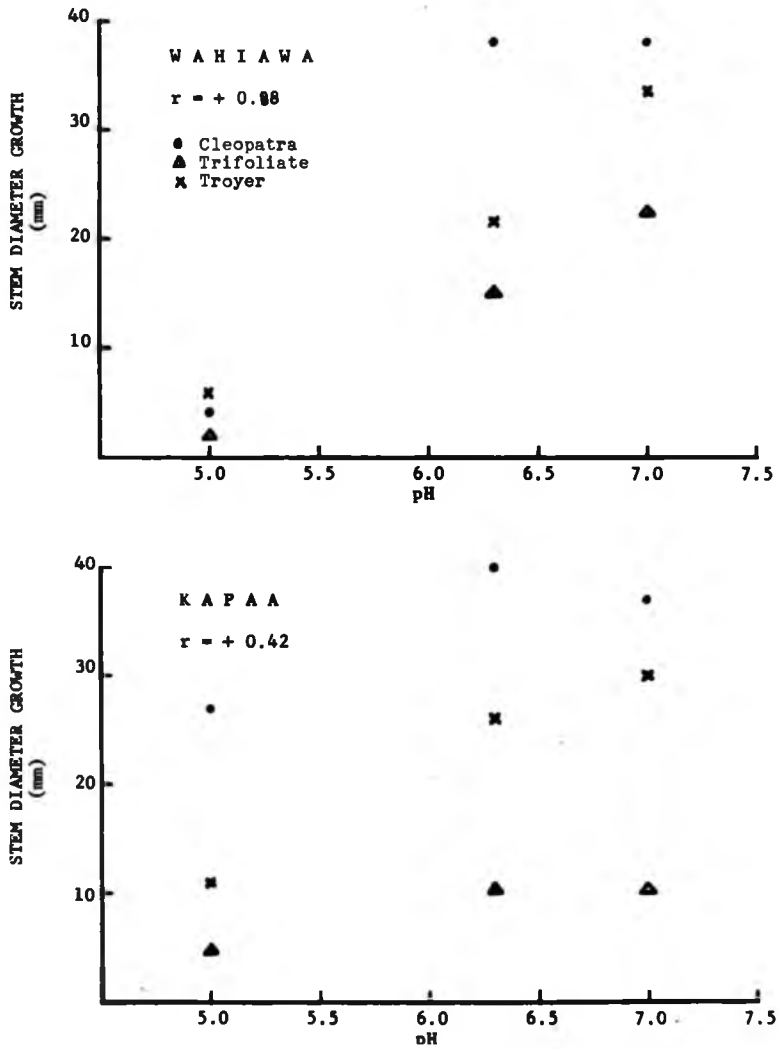

FIG. 11. RELATIONSHIPS BETWEEN STEM DIAMETER GROWTH AND pH OF THE SOIL

iron with other elements has been reported. The work of Lohnis (1960), with various grass, legume and tuberous crops, indicated that calcium and magnesium reduced the uptake of manganese.

Vlamis and Williams (1962) investigated the competitive effects of elements on manganese solubility. An increased absorption of manganese reduced the effect of iron, potassium, and magnesium for plant growth. They further stated that calcium, magnesium and ammonium were more effective than potassium and sodium in repressing manganese uptake.

The increase in growth of Trifoliate at the higher pH levels was not comparable to the other two species studied even when the solubility of manganese was reduced. This investigation indicated that manganese was more important than aluminum as a growth limiting factor, especially with Trifoliate orange. This shows that Trifoliate may be more sensitive to excessive manganese and aluminum concentrations than the other two species. By observation, the root distribution of Trifoliate was increasingly better with higher pH. At pH 5.0, roots were very few but at pH 7.0 the roots were well distributed in the soil. This was true for both soils with only a minor difference in the magnitude of root growth.

Distribution of root growth of Troyer was less than Cleopatra but greater than Trifoliate. This was true for all pH levels but with some difference in magnitude of root

growth. Roots of Cleopatra were well distributed throughout the pot at higher pH levels.

This would suggest that Cleopatra may have some organic acid emitted at the root tips to chelate the aluminum and manganese and reduce their uptake. It seems probable that Cleopatra has the ability or mechanism to reduce manganese and aluminum uptake and increase plant growth, because it eliminates some antagonistic effects of other nutrients. The only evidence available to support this is the low content of aluminum and manganese in Cleopatra and high concentration in Troyer and Trifoliate seedlings and the distribution of the root development of these citrus seedlings. The work of Foy (1964) showed that the high tolerance of some plants to aluminum may have this chelating organic acid emitted at the root tips. This is highly speculative but is important and warrants further investigation.

Experiment 2. Effect of photoperiod on growth of three citrus rootstock seedlings

The effect of photoperiod on the growth of citrus species showed that seedlings grown with supplemental light produced more growth than under the short day treatment (Table 14 and Fig. 12 and 13). Earlier flushes were observed under the long day treatments than normal or short days. Shoot growth increase for Trifoliate was 24 cm greater and for Troyer 46 cm greater under long days than short days. These differences were significant at the 1% level. The increase

TABLE 14. EFFECT OF PHOTOPERIOD ON GROWTH INCREASE OF CITRUS ROOTSTOCK SEEDLINGS

Rootstock and Photoperiod (hr)	Stem Diameter mm/plant [a]	Shoot Length cm/plant [a]	Fresh Weight g/plant [a]	Number of Branches per/plant [b]
Trifoliate				
8-hour day	8.0 a	23.5 a	26.8 a	3 a
12-hour day	9.4 b	30.7 b	32.8 b	4 b
16-hour day	15.5 c	47.2 c	62.0 c	6 c
Troyer				
8-hour day	10.9 b	54.0 d	58.4 c	7 c
12-hour day	15.2 c	64.4 e	88.7 d	6 cd
16-hour day	24.3 d	100.4 f	136.6 e	5 d
Cleopatra				
8-hour day	15.2 c	44.5 c	107.5 f	2 a
12-hour day	18.6 e	51.0 c	126.3 f	4 b
16-hour day	22.1 f	57.4 d	161.0 g	5 d

a/ Means of 8 plants
b/ Means of 4 plants

Means followed by different letters are statistically different at 1% level.

FIG. 12. PHOTOPERIOD EFFECTS ON GROWTH OF CLEOPATRA MANDARIN ROOTSTOCK SEEDLINGS

FIG. 13. PHOTOPERIOD EFFECTS ON GROWTH OF TRIFOLIATE ORANGE AND TROYER CITRANGE ROOTSTOCK SEEDLINGS

in shoot growth of Cleopatra under long days was not as great as that of Trifoliate and Troyer seedlings.

Highly significant growth differences in all growth measurements were found between treatments for each rootstock (Table 14 and Appendix Tables 3 and 4). The growth of Troyer under supplemental light was much greater than the growth of Trifoliate.

The differences in fresh weight production was considerable between both treatments and species. Seedlings grown under supplemental light had significantly higher fresh weight compared to the short day or normal day treatments. However, the increase in fresh weight of Cleopatra between 8-hour and 12-hour day was not significant.

Cleopatra mandarin produced more fresh weight increase than Trifoliate or Troyer at each of the three daylengths. If the fresh weights of the three treatments are totaled, Cleopatra mandarin produced about 61% more than Trifoliate and about 32% more fresh weight than Troyer. It is inherently much less sensitive to short daylengths. This may be presumed to be a contributing factor to the better adaptability of mandarin oranges in the tropics than other orange species.

SUMMARY

Seedlings of Trifoliate orange (*Poncirus trifoliata*), Troyer citrange (*P. trifoliata* x *Citrus sinensis*) and Cleopatra mandarin (*Citrus reticulata*), were planted in Kapaa and Wahiawa soil types which were adjusted to pH levels of 5.0, 6.3 and 7.0 and fortified with uniform applications of N,P,K, Zn and B. Kapaa, an Aluminous Ferruginous Latosol, is highly leached, has a pH of 5.0 or below and has excessive amounts of soluble aluminum and iron. Wahiawa, a Low Humic Latosol, with a pH of about 5.0, contains excessive levels of soluble manganese.

Measurements of shoot growth, stem diameter, number of branches and fresh weight increase were made after 12 months. Leaf samples were analyzed for Al, Mn, Fe, Ca and P. The cation-exchange capacity (CEC) of the soil and roots and the exchangeable cations of the soil were determined.

All 3 rootstocks produced more new growth on Kapaa soil than on Wahiawa, the mean stem diameter increases being 41.8 mm and 27.7 mm, respectively. All the seedlings grew poorly at pH 5.0 on Wahiawa and all except Cleopatra on Kapaa soil. Trifoliate seedlings did not produce enough leaves for analysis at pH 5.

Leaf content of manganese, aluminum and iron decreased, and the calcium increased as the soil pH increased from 5 to 7. Stem diameter increase showed a high negative correlation

with leaf content of aluminum and manganese. The four ratios of calcium and phosphorus to aluminum and manganese were positively correlated to stem diameter increase. Manganese proved to be a more important growth limiting factor than aluminum.

Kapaa soil had a much higher CEC of 28 me than the 10 me of Wahiawa soil and a higher content of exchangeable aluminum. Cleopatra mandarin made the best growth on Kapaa soil at pH 6.3 and 7.0 and poorest at pH 5.0 on Wahiawa. Troyer citrange made the best growth at pH 7.0 on both soils. Trifoliate orange grew best on both soils at pH 6.3 but not significantly better than at pH 7.0.

Daylength may be important in growth of Trifoliate and Troyer seedlings. Rootstocks were subjected to photoperiods of 8 hours, 11 to 12 hours, the normal day for Hawaiian winter and Hawaiian normal day plus 4 hours of supplemental light. Growth of Trifoliate and Troyer was significantly greater under the long photoperiod compared to the 8 hour day. Cleopatra mandarin was much less affected by photoperiod and made more growth at all three daylengths than Troyer or Trifoliate seedlings.

The factors studied in this research project indicate that the growth of Trifoliate orange seedlings can be improved in Hawaii by using supplementary light on the nursery stock, and soil with pH of 6.0 to 6.5 with well drained soil supplied frequently with available nutrients particularly phosphorus, calcium, iron and other micronutrients.

APPENDIX

APPENDIX

TABLE 1. ANALYSIS OF VARIANCE OF INCREASE IN STEM DIAMETER, LENGTH, NUMBER OF BRANCHES OF THREE ROOTSTOCKS IN TWO SOILS AT THREE pH LEVELS

Source of Variation	D.F	Stem diameter growth M.S.	Shoot Length M.S.	Number of branches M.S.
Replications	7	150.5	3995.5	1.2
Treatments	17	2169.8**	66185.4**	29.2**
Rootstocks	2	6977.5**	272996.6**	93.0**
Soils	1	3201.7**	197929.8**	15.3**
pH	2	1407.7**	132490.7**	129.6**
Soils X rootstocks	2	1498.0**	39001.4**	8.7**
Soils X pH	2	68.0	257.7	2.2
Rootstock X pH	4	658.4**	2451.2**	2.6
Rootstock X pH X soils	4	281.1*	6983.7*	1.2
Error	119	105.2	1448.4	22.6

* - Significant at 5% level
** - Significant at 1% level

TABLE 2. ANALYSIS OF VARIANCE OF INCREASE IN FRESH WEIGHT OF THREE ROOTSTOCKS GROWN IN TWO SOILS AT THREE pH LEVELS..

Source of Variation	D.F.	M.S.
Replications	2	10757.2
Treatments	(17)	66551.0**
Rootstocks	2	257080.7**
Soils	1	134901.1**
pH	2	75383.5**
Soils X rootstocks	2	109066.3**
Soils X pH	2	4083.4
Rootstock X pH	4	17439.8
Rootstock X pH X soils	4	3845.8
Error	32	9214.3

* Significant at 5% level
** Significant at 1% level

TABLE 3. ANALYSES OF VARIANCE OF DATA PRESENTED IN THE APPENDIX OF INCREASE IN STEM DIAMETER, SHOOT LENGTH, NUMBER OF BRANCHES OF THREE CITRUS ROOTSTOCKS UNDER THREE PHOTOPERIODS

Source of Variation	D.F.	Stem diameter growth M.S.	Shoot length M.S.	Number of Branches M.S.
Main Plot				
Photoperiods	2	576.2**	4846.9**	11.0**
Block	7	3.1**	15.4	0.51
Error (a)	14	1.8	25.9	0.86
Split Plot				
Rootstocks	2	263.0**	9321.9**	31.4**
Rootstocks x Photoperiods	4	31.4**	686.1**	9.3**
Error (b)	42	0.5	65.2	1.7

**Significant at 1% level

TABLE 4. ANALYSES OF VARIANCE OF DATA PRESENTED IN THE APPENDIX OF INCREASE FRESH WEIGHT OF THREE CITRUS ROOTSTOCKS UNDER THREE PHOTOPERIODS

Source of Variation	DF	Fresh Weight M.S.
Main Plot		
Photoperiods	2	9623.1**
Block	3	9.2
Error (a)	6	34.6
Split Plot		
Rootstocks	2	25148.5**
Rootstocks X Photoperiods	4	475.3 **
Error (b)	18	16.0

**Significant at 1% level.

LITERATURE CITED

Batchelor, H.J., and H.J. Webber. 1948. Citrus industry. Univ. Calif. Press., Berkeley. 1:113-130.

Black, C.A. 1963. Soil-plant relationships. 3rd ed. John Wiley & Sons, Inc. New York. p 118-122.

Bitters, W.P., and L.D. Butchelor. 1950. Effects of root-stocks on the size of orange fruits. Amer. Soc. Hort. Sci. Proc. 57:133-141.

Blair, A.W., and A.L. Prince. 1926. The relation of soil reaction to active aluminum. Soil Sci. 24:205-213.

Cameron, S.H., R.T. Mueller, A. Wallace, and E. Sartori. 1952. Influence of age of leaf, season of growth and fruit production on the size and inorganic composition of Valencia Orange leaves. Proc. Amer. Soc. Hort. Sci. 60:42-50.

Cathey, H.M., and A.A. Piringer. 1961. Relation of phosfon to photoperiod, kind of supplemental light, and night temperature on growth and flowering of garden annuals. Proc. Amer. Soc. Hort. Sci. 77:608-619.

Chandler, W.H. 1958. Evergreen orchards. Lea and Febiger, Philadelphia. p 125-128.

Chapman, H.D., and P.F. Pratt. 1961. Methods of analysis for soils, plants, and waters. Univ. of Calif. Agr. Sci. Berkeley. 309 p.

Christensen, P.D., S.J. Toth, and F.E. Bear. 1950. The status of soil manganese as influenced by moisture organic matter and pH. Soil Sci. Amer. Proc. 15:279-282.

Chu, Ada C., and G.D. Sherman. 1952. Differential fixation of phosphate by typical soils of the Hawaiian great soil groups. Hawaii Agr. Exp. Sta. Tech. Bull. 16. 20 p.

Cooper, W.C., B.S. Gorton, and E.O. Olson. 1952. Ionic accumulation in citrus as influenced by rootstock and scion and concentration of salts and boron in the substrate. Plant Physiol. 27:191-203.

Crooke, W.M. 1958. Effect of heavy-metal toxicity on the cation-exchange capacity of plant roots. Soil Sci. 86:231-240.

_____, and A.H. Knight. 1962. An evaluation of published data on the mineral composition of plants in the light of cation-exchange capacities of their roots. Soil Sci. 93:365-373.

_____,_____,and I.R. Macdonald. 1961. Cation exchange properties and pectin content of storage-tissue disks. Plant and Soil. 13:55-67.

DeDatta, S.K., R.L. Fox, and G.D. Sherman. 1963. Availability of fertilizer phosphorus in three latosols of Hawaii. Agron. Jour. 55:311-313.

Downs, R.J., and H.A. Borthwick. 1956. Effect of photoperiod upon vegetative growth of Weigela florida var. variegata. Proc. Amer. Soc. Hort. Sci. 68:518-521.

Drake, M., J. Vengris, and W.G. Colby. 1951. Cation-exchange capacity of plant roots. Soil Sci. 72:139-147.

Embleton, T.W., W.W. Jones, and C.K. Labanauskas. 1962. Sampling orange leaves--leaf position important. California Citrograph 47(2):382-396.

_____,C.K. Labanauska, and W.P. Bitters. 1962. Rootstock effect on boron, other elements in leaves. California Citrograph 47:230.

Epstein, E. 1956. Mineral nutrition of plants: mechanisms of uptake and transport. Ann. Rev. Plant Physiol. 7:1-24.

Ford, H.W. 1953. The influence of rootstock and tree age on root distribution of citrus. Proc. Amer. Soc. Hort. Sci. 63:137-142.

Fox, R.L., and B. Kacar. 1964. Phosphorus mobilization in a calcareous soil in relation to surface properties of roots and cation uptake. Plant and Soil. 20:319-330.

_____,_____. 1965. Mobilization of non-exchangeable potassium and sodium in a calcareous soil during plant growth. Plant and Soil. 22:33-43.

_____, _____, and G.D. Sherman. 1962. Phosphorus solubility and availability to plants and the aluminum status of Hawaiian soils as influenced by liming. International Soil Conference, New Zealand, 12 p.

Foy, C.B. and J.C. Brown. 1964. Toxic factors in acid soils. II. Differential aluminum tolerance of plant species. Soil Sci. Soc. Amer. Proc. 28:27-32.

Fujimoto, C.K., and G.D. Sherman. 1947. Manganese availability as influenced by stem sterilization of soils. Jour. Amer. Soc. Agron. 40:527-534.

_____, _____. 1948. Behavior of manganese in the soil and the manganese cycle. Soil Sci. 66:131-145.

Furr, J.R., W.C. Cooper, and P.C. Reese. 1947. An investigation of flower formation in adult and juvenile citrus trees. Amer. Jour. Bot. 34:1-8.

Gerloff, G.C. 1963. Comparative mineral nutrition of plants. Ann. Rev. Plant Physiol. 14:107-123.

Gilbert, B.E., and F.R. Pember. 1931. Further evidence concerning the toxic action of aluminum in connection with plant growth. Soil Sci. 31:267-273.

Gustafson, F.G. 1938. Influence of the length of day on the dormancy of the seedlings. Plant Physiol. 13:655-658.

Hale, J.B., and S.G. Heintze. 1946. Manganese toxicity affecting crops on acid soils. Nature 157:554-556.

Hass, A.R.C. 1932. Injurious effects of manganese and iron deficiencies on the growth of citrus. Hilligardia 7:181-206.

_____. 1936. Phosphorus nutrition of citrus and the beneficial effect of aluminum. Soil Sci. 42:187-198.

_____. 1945. Influence of the rootstock on the composition of citrus leaves and rootlets. Soil Sci. 60:445-461.

_____. 1947. Effects of the rootstock on the composition of citrus trees and fruit. Plant Physiol. 23:309-330.

_____, and F.F. Halma. 1931. Sap concentration and inorganic constituents of mature citrus leaves. Hilligardia 5:407-424.

Hamilton, R.A., and E.T. Fukunaga. 1962. Better rootstocks for citrus growth in Hawaii. Univ. of Hawaii Coop. Ext. Serv. Cir. 397. 12 p.

Heintze, S.G. 1961. Studies on cation-exchange capacities of root. Plant and Soil 13:365-381.

Holmes, W.E., M. Takahashi, and G.D. Sherman. 1960. Distribution of gibbsite and kaolinite with depth in a gibbsitic soil on Kauai. Hawaii Agr. Exp. Sta. Tech. Prog. Rpt. 125. 15 p.

Hopkins, E.F. 1930. The necessity and function of manganese in the growth of chlorella. Science n.s. 72:609-610.

Jackson, M.L. 1958. Soil chemical analysis. Prentice Hall, Inc. Englewood, N.J. p 57-64.

Jenny, H., and R. Overstreet. 1938. Cation-exchange capacity between plant roots and colloids. Soil Sci. 47:257-272.

Johanson, M.O. 1924. Manganese chlorosis of pineapples: its cause and control. Hawaii Agr. Exp. Sta. Bull. 52. 37 p.

Kacar, B. 1962. Plant and soil analysis. Univ. of Nebraska Agr. Sci. 45 p.

Kanehiro, Y., and A.T. Chang. 1956. Cation-exchange properties of the Hawaiian great soil groups. Hawaii Agr. Exp. Sta. Tech. Bull. 31. 27 p.

_____, and G.D. Sherman. 1956. Effect of dehydration-rehydration on cation-exchange capacity of Hawaiian soils. Soil Sci. Soc. Amer. Proc. 20:341-344.

Kelley, W.P. 1909. The influence of manganese on the growth of pineapples. Hawaii Agr. Exp. Sta. Bull. 23. 14 p.

_____, and Cummins, A.B. 1920. Composition of normal and mottled citrus leaves. Jour. Agr. Res. 20:161-191.

Kramer, P.J. 1936. Effect of variation in length of day on growth and dormancy of trees. Plant Physiol. 11:127-137.

Labanauskas, C.K. 1962. Correction of manganese deficiencies in grapefruit trees by foliar sprays in desert areas of Southern California. Proc. Amer. Soc. Hort. Sci. 80:268-273.

Lammerts, W.E. 1941. A Royal Apricot sport of short chilling requirement: origin and transmission of characteristics to seedlings. Proc. Amer. Soc. Hort. Sci. 38:175-178.

Lamphear, F.O., and R.P. Meahl. 1961. The effect of various photoperiod on rooting and subsequent growth of selected woody ornamental plants. Proc. Amer. Soc. Hort. Sci. 77:620-634.

Larsen, J.E., G.F. Warren, and R. Langston. 1959. Effect of iron, aluminum and humic acid on phosphorus fixation by organic soils. Soil Sci. Soc. Amer. Proc. 23:438-440.

Laties, G.G. 1959. Active transport of salt into plant tissue. Ann. Rev. Plant Physiol. 10:87-112.

Lesley, J.W. 1944. Peach breeding in relation to winter chilling requirement. Proc. Amer. Soc. Hort. Sci. 45:243-250.

Liebig, G.F., A.P. Vanselow and H.D. Chapman, 1942. Effects of aluminum on copper toxicity, as revealed by solution-culture and spectographic studies of citrus. Soil Sci. 53:341-351.

Lignon, W.S. and W.H. Pierre. 1932. Soluble aluminum studies. II Soil Sci. 34:307-322.

Lohnis, M.P. 1960. Effect of magnesium and calcium supply on the uptake of manganese by various crop plants. Plant and Soil 12:339-374.

Maginnes, E.A., and R.W. Langhans. 1961. The effect of photoperiod and temperature on initiation and flowering of snapdragon (Antirrhinum majus - var. Jackpot) Proc. Amer. Soc. Hort. Sci. 77:600-607.

Magistad, O.C. 1925. The aluminum content of the soil solution and its relation to soil reaction and plant growth. Soil Sci. 20:181-225.

Martin, J.P. 1960. Fungi and nematodes in South African citrus orchard soils in relation to the citrus replant problem. Soil Sci. Soc. Amer. Proc. 24:469-472.

_____, and A.L. Page. 1962. Influence of pH on growth and chemical composition of seedlings. California Citrograph 48:2-3, 21-22.

Matsusaka, Y. and G.D. Sherman. 1950. Titration curves and suffering capacities of Hawaiian soils. Hawaii Agr. Exp. Sta. Tech. Bull. 11. 36 p.

McLean, E.O., D. Adams, and R.E. Franklin. 1956. Cation-exchange capacities of plant roots as related to their nitrogen contents. Soil Sci. Soc. Amer. Proc. 20:345-347.

Mehlich, A., and J.F. Reed. 1948. Effects of cation-exchange properties of soil on the cation content of plants. Soil Sci. 66:289-306.

Nakamura, M.T., and G.D. Sherman. 1961. The Vandium content of Hawaiian Island soils. Hawaii Agr. Exp. Sta. Tech. Bull. 45. 20 p.

Nitsch, J.P. 1957. Growth responses of woody plants to photoperiodic stimuli. Proc. Amer. Soc. Hort. Sci. 70:512-525.

Parker, E.R. 1948. Selection of orchard sites, p 238-239. In L.D. Batchelor and H.J. Webber, The citrus industry II. Univ. of Calif. Press, Berkeley.

Paul, L.G., and H.D. Chapman. 1944. Some effects of pH on the growth of citrus in sand and solution cultures. Soil Sci. 58:455-465.

Piringer, A.A., R.J. Downs, and H.A. Borthwick. 1961. Effects of photoperiod and kind of supplemental light on the growth of three species of citrus and Poncirus trifoliata. Proc. Amer. Soc. Hort. Sci. 77:202-210.

_____, and R.J. Downs. 1959. Response of apple and peach trees to various photoperiods. Proc. Amer. Soc. Hort. Sci. 73:9-15.

Plucknett, D.L., J.C. Moomaw, and C.H. Lamoureux. 1963. Root development in aluminous Hawaiian soils. Pacific Sci. 17:398-405.

Rains, D.W., W.E. Schmid, and E. Epstein. 1964. Absorption of cations by roots. Effects of hydrogen ions and essential role of calcium. Plant Physiol. 39:274-278.

Ray, M.P. 1958. Destruction of auxin. Ann. Rev. Plant Physiol. 9:81-118.

Reuther, W., T.W. Embleton, and W.W. Jones. 1958. Mineral nutrition of tree crops. Ann. Rev. Plant Physiol. 9:175-206.

Robert, C.J., Koo and J.W. Sites. 1956. Mineral composition of citrus leaves and fruits as associated with position on the tree. Proc. Amer. Soc. Hort. Sci. 68:245-252.

Russell, E.J. 1961. Soil conditions and plant growth. 9th ed. Logmans, Green & Co., London. p 523-534.

Salisbury, F.B. 1960. Photoperiodism and the flowering process. Ann. Rev. Plant Physiol. 12:293-321.

Schmehl, W.R., M. Peech, and R. Bradfield. 1950. Causes of poor growth of plants on acid soils and beneficial effects of liming: I. Evaluation of factors responsible for acid soil injury. Soil Sci. 70:393-410.

Shannon, L.M., and J. Zaphrir. 1957. The relative influence of two citrus rootstock species upon plant growth and upon the inorganic composition of the scion. Proc. Amer. Soc. Hort. Sci. 71:257-264.

Sinclair, W.B. 1961. The orange. Univ. of Calif., Div. of Agr. Sci. p 72-79.

Smith, P.F., W. Reuther, and A.W. Specht. 1948. The influence of rootstock on the mineral composition of valencia orange leaves. Plant Physiol. 24:455-460.

Smith, R.L., and A. Wallace. 1954. Preliminary studies of some physiological root characteristics in citrus and avocado. 63:143-145.

Snyder, W.E. 1955. Effect of photoperiod on cuttings of Taxus cuspidata while in the propagation bench and during the first growing season. Proc. Amer. Hort. Sci. 66:397-402.

Somers, I.I., and J.W. Shive. 1942. The iron-manganese relation in plant metabolism. Plant Physiol. 17:582-602.

Suehisa, R.H., O.R. Younge, and G.D. Sherman. 1963. Effects of silicates on phosphorus availability to Sudan grass grown on Hawaiian soils. Hawaii Agr. Exp. Sta. Tech. Bull. 51. 40 p.

Tamura, T., M.L. Jackson, and G.D. Sherman. 1953. Mineral content of low humic, humic, and hydrohumic latosols of Hawaii. Soil Sci. Soc. Amer. Proc. 17:343-346.

Truog, E. 1918. Soil acidity: I. Its relation to the growth of plants. Soil Sci. 5:169-193.

Vlamis, J., and P.E. Williams. 1962. Ion competition in manganese uptake by barley plants. Plant Physiol. 37:650-655.

Wallace, A., G.P. North, and E. Frolich. 1953. Interactions of rootstock, soil pH, and nitrogen on the growth and mineral composition of small lemon trees in a greenhouse. Proc. Amer. Soc. Hort. Sci. 62:75-78.

Wallace, T., E.J. Hewitt, and B.J.D. Nicholas. 1945. Determination of factors injurious to plants in acid soils. Nature 156:778-779.

Wareing, P.F. 1948. Photoperiodism in woody species. Forestry. 22:211-222.

Weinberger, J.H. 1950. Prolonged dormancy of peaches. Proc. Amer. Soc. Hort. Sci. 56:129-133.

Williams, D.E., and N.T. Coleman. 1950. Cation-exchange properties of plant root surfaces. Plant and Soil 2:243-256.

Young, R.H. 1961. Influence of clay length, light intensity, and temperature on growth, dormancy, and cold-hardiness of Red Blush grapefruit trees. Proc. Amer. Soc. Hort. Sci. 78:174-180.